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FIRE

in the Northern Environment



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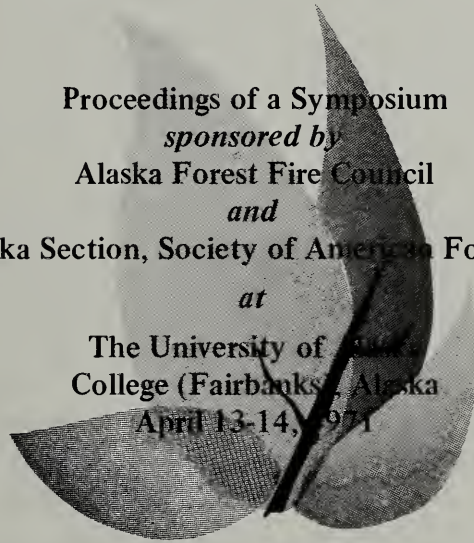
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Cover photos: Fire crowning in spruce near Kenai in the Swanson River area.
Wildfire in the vast roadless taiga.

Fire in the Northern Environment— A Symposium

Proceedings of a Symposium
sponsored by
Alaska Forest Fire Council
and
Alaska Section, Society of American Foresters
at

The University of Alaska
College (Fairbanks, Alaska)
April 13-14, 1971



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CATALOGING - PREP.

Edited by
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Preface

A symposium on Fire in the Northern Environment was held April 13th and 14th, 1971, at the University of Alaska, College, Alaska. The symposium was sponsored by the Alaska Forest Fire Council and the Alaska Section, Society of American Foresters.

The Alaska Forest Fire Council (AFFCO) was formally established on April 3, 1969, with the primary objective being "to provide a forum to coordinate and promote activities related to wildland fires and their effects." Early in 1970 the idea arose that a symposium be organized to discuss wildfire in interior Alaska. Such a meeting would provide an opportunity to explore the current state of knowledge of wildfire and its interrelations in the Alaskan environment. The outcome could serve as a basis for future recommendations on needed areas of research in this broad field. Following the initial decision to hold this meeting, the Alaska Section, Society of American Foresters, joined with AFFCO to provide moral and financial support for the symposium.

The purpose of this symposium was to explore some aspects of wildfire in the subarctic. We hoped to delineate and clarify many of the current questions and opinions on wildfire in the subarctic—its relationship to the natural environment and to man's use of that environment—as well as to consider some aspects of fire control in this region. Participation was solicited from all persons having an interest in the subject—researchers, recreationists, natural resource managers, and private citizens were welcomed. Opportunities were provided to ask questions, air individual viewpoints, and develop given topics in greater depth.

The symposium opened Tuesday, April 13th, with a welcome from Dr. E. H. Beistline, Provost, University of Alaska. Additional introductions were made by Dr. C. W. Slaughter, Symposium Chairman, and Mr. A. L. Comiskey, current AFFCO president. Immediately following Dr. E. V. Komarek's stimulating keynote address, attention turned to presentation of formal papers and discussions. Technical sessions were competently led by session chairmen: Dr. E. V. Komarek, Tall Timbers Research Station; Mr. A. M. Roberts, General Counsel for the Western Forestry and Conservation Association; Mr. R. C. Krumm, Fairbanks District Manager, U.S. Bureau of Land Management; and Dr. F. C. Dean, College of Biological Sciences and Renewable Resources, University of Alaska. More than 115 people were in attendance at the opening session, and 97 individuals formally registered for the 2-day symposium. The evening of April 13th a banquet was held at the Ft. Wainwright Officers' Open Mess. Mr. Jerry Zamber, U.S. Bureau of Land Management, addressed the group on the subject of the proposed trans-Alaska oil pipeline.

It would be presumptuous to imply that all topics relevant to subarctic wildfire-environment relationships were even mentioned, let alone fully

explored during these sessions. However, it is safe to state that this meeting was a “first” in Alaska in attempting to draw together natural resource managers, fire control specialists, scientists, and private citizens to explore jointly some of the ramifications of wildfire, its control and role in the subarctic.

The papers in these proceedings have been assembled in order of their presentation at the conference. In addition to the formal papers, transcripts of the panel discussions and the summary commentary of Dr. E. V. Komarek are included.



Acknowledgments

On behalf of the Alaska Forest Fire Council and the Alaska Section, Society of American Foresters, we wish to thank the speakers for their contribution to these proceedings and all participants for making it a successful meeting. Dr. Earl Beistline, Provost of the University of Alaska, and Dr. Keith Mather, Director of the Geophysical Institute, University of Alaska, were most courteous in providing their facilities and services for this meeting. We would like to thank Dr. E. V. Komarek, Sr., of Tall Timbers Research Station, for his assistance and support of the entire endeavor.

A special thanks is due to the clerical and technician staff of the Forestry Sciences Laboratory, U.S. Forest Service, College, Alaska, and the Alaska Field Station, USACRREL, for their untiring help in preparing for and presenting this meeting. Personnel of the Fairbanks District, U.S. Bureau of Land Management, provided invaluable transportation and logistics support for out-of-town participants.

The editorial support of Mr. George M. Hansen, Pacific Northwest Forest and Range Experiment Station, and his staff—particularly Mrs. Betty Bell—is gratefully acknowledged.

Acknowledgment is due the Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture for publishing these proceedings. The Bureau of Land Management of the U.S. Department of the Interior, the U.S. Army Cold Regions Research and Engineering Laboratory, the Alaska Section, Society of American Foresters, and the Alaska Forest Fire Council helped to defray costs.

Charles W. Slaughter
Symposium Chairman



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KEYNOTE ADDRESS

by

E. V. Komarek, Sr.



Principles of fire ecology and fire management in relation to the Alaskan environment

Abstract

Fire ecology is discussed in relation to basic ecological processes; the characteristics of the fire environment are reviewed. Lightning and lightning storms are considered as the primary natural cause of fires in nature. The nature of fire and its relationship to plants, animals, and soils are briefly examined. The effects of fire in Alaska are mentioned in relation to its occurrence before and after occupancy by early man, Eskimo, Indian, and the European. Differences in viewpoint between fire management and fire control are discussed. The need for fire management research in Alaska is stressed in relation to the management of forest, wildlife, watershed, recreation, and urban lands.

E. V. Komarek, Sr.
Tall Timbers
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Several separate incidents culminate in this privilege of speaking before you on the principles of fire ecology and fire management in relation to the Alaskan environment. At one time, I had been led to believe that fire had no natural place in the boreal environment, even after a quarter of a century of studies in fire ecology.

My personal contacts with the unique circumpolar boreal forest habitat had been limited to only the southernmost outposts of this interesting community in Wisconsin (13), and in the Great Smoky Mountains of Tennessee and North Carolina (23). However, study of small mammals by my wife and me in southern Georgia and in northern Florida (some in what is now the Tall Timbers Research Station) had impressed me of the consistent beneficial effect that fires had on the habitats of certain small mammals as well as on that of the bobwhite quail (*Colinus virginianus*) (33, 34). This in turn created a nagging doubt that my ideas or opinions about fire and the boreal forest were correct. As a final consequence, we set out to make field studies in Canada and Alaska.

Our first stop at the district forester's office in Port Arthur will never be forgotten because his remarks and those of his staff were to the effect that at least 95 percent of the boreal forest of Canada had regenerated on burned

land. This led us to travel into Alaska, covering nearly all of the existing paved or gravel roads and camping in many diverse habitats. These visits, as well as an in-depth literature survey, familiarized me with the extensive literature on the Canadian boreal forest. Much of this literature, particularly some 10 or 15 years ago, was not readily available in the lower 48 States. In fact, apparently that which was available was not read even in Alaska, for at my last stop here, which was at a Forest Experiment Station, I was told that lightning fires occurred only rarely and were of no consequence in interior Alaska which is contrary to what I had read. This then was my introduction to the fire ecology and fire management problems in the Alaskan environment.

The cooperation of the Canadian and the Yukon Territory Forest Services is gratefully acknowledged. With their help, it was possible to see many diverse habitats from Nova Scotia to British Columbia, including an over-mature spruce forest some 300 years old.

When your symposium chairman, Dr. Slaughter, suggested that I present the keynote address at this symposium I went quickly to a dictionary for a definition of such a talk. I found, in essence, that a keynote address is a speech, usually at a political gathering, that presents the principal issues in which those present are interested. Understanding that you do have politics in Alaska, in particular pertaining to a certain useful substance and not wishing to get embroiled in that, for fire problems have sufficient heat by themselves, I sought further enlightenment. I then discovered that "keynote" meant that such a talk should be concerned with the basic or ruling aspects. Therefore, I will limit myself to the principles of fire ecology and the topic that fire management, to be successful, must be based on these principles. Note, however, that I have used the words "fire management" and not fire control, for the latter usually implies only fire exclusion.

Fire Ecology

Fire ecology is the scientific study of fire's effect on the environment, the interrelationships of plants, and the animals that live in such habitats. The principles of fire ecology are based on certain physical and biological laws. These are discussed briefly here.

Conservation of matter and energy.—The planet earth is one small part of the universe, but all of its processes follow the three laws of thermodynamics. The first of these is the law of conservation of matter and energy and is pertinent to this discussion. This simply means that neither matter nor energy is ever destroyed but can only change its form. Burning by any means, even by man, in reality destroys nothing; it is only a change of one form of matter or energy to another. This, of course, comes as quite a shock to those people who believe fires, as so often reported, destroy acres of vegetation and land.

Major physical forces.—Two major physical forces are interrelated and also must be considered in our attempt to understand the principles of fire ecology: (1) fire or rapid oxidation, the changing of organic matter back to its original components—water, CO₂, and minerals—and (2) electricity as the energy source needed to initiate rapid oxidation. The physical form of fire or rapid oxidation is familiar. One of the most obvious physical features of electricity is the lightning bolt, a function of the activity of the changing electrical field of the earth, usually produced in connection with thunderstorms. Because of this vast discharge of energy and the resulting heat at the point of impact on the earth's surface, the temperature is raised well above the kindling point of the plant material.

Basic ecological processes.—There are certain basic ecological processes that must be considered in a discussion on fire ecology and fire management because of the impact or effect of fire or fire exclusion. Time and space will allow me only briefly to mention these processes, but they should be kept constantly in mind in the following discussion. They are:

1. Change — Always there is change. This is fundamental. All living things change by metabolic processes and by natural selection and evolution.
2. Continuity — Species cannot live successfully as individuals but only through reproduction. Individuals are born, they grow and mature, and they die. Any species becomes extinct if the continuity is broken.
3. Diversity — No two individuals, plants or animals, are exactly alike and so no two species or communities can be exactly alike.
4. Succession — This is the more or less orderly pattern of events and processes in nature whereby plant and animal species replace each other as a result of a changing environment.
5. Competition — Living things must compete with each other for nutrients, light, water, space, etc.
6. Cooperation — Plants and animals live together in an environment, each to its niche, and frequently contribute to each other's biological economy.
7. Metabolism — Waste results from metabolism, and death would soon overwhelm the earth if there were no processes to change and recycle such refuse. Waste must be changed to be removed because no living thing can live in its own waste.
8. Adaptation — Living things must have a dwelling place, each with specific environmental requirements.

The action of fire on these eight major ecological processes is exceedingly diverse and extensive. Fire exclusion likewise has an important impact on all of these. It is this great difference in effect, fire and/or fire exclusion, that

gives the land manager a most important tool in the management of lands for certain specific purposes.

Fire characteristics.—The place of fire in nature has been responsible for discussions as heated as the raging crown fire in spruce stands and as obscure and dense as the smoke from a deep-seated wet peat fire. Because of this, I will have to point out some very elemental features which are so commonplace that they are rarely taken into consideration. The first of these is that the heat of a fire is above the burning substance, not below it. The second, one of the main reasons fire discussions have been so controversial, is that no two fires are alike; they are like living things, they change constantly. Scientific studies, otherwise of excellent quality and design, are usually conducted without regard to the kind of fire that occurred—when or where it occurred in relation to the life pattern of growing things; the kind, character, and amount of fuel that fed the fire; and particularly, over how long a period fire had been excluded either by man or by nature. Usually no history of the area where the fire occurred and of man's possible disruption of natural conditions is even considered, although it may be available.

Fire and the environment.—The impact of fire changes the relationships between the plant and animal communities as well as between them and the climate. Fire also confuses the interpretation of ecological research, creates situations of apparent conflict, and torments the investigator because of the extreme variation of fires and their dependence for effect on a great many variable factors. Fire research, particularly, becomes difficult if related to small, isolated, or specialized investigations.

The emphasis for the past century or so has centered on the forest; whereas, this is only a very small part of the ecosystem as far as the total interrelation is concerned. Few animals, particularly vertebrate animals including man, receive much from trees in the way of food during any 12-month period. Without the tropical rain-forest animals, the list of mammals that depend on trees is small indeed. In my opinion, the place of the forest in the total ecosystem has been exaggerated, and it is time to consider just how necessary it is as the natural environment or habitat of major ecosystems.

In all too many instances, we have tried to develop the most intricate and sophisticated investigations instead of first trying to learn the general pattern and then going into detailed studies. Permanent fixed points regularly photographed will not require a great deal of time, effort, or funds. Naturally replicated plots of considerable size will yield still more data. In fact, I feel that the greatest hazard in applying a fixed-point photographic study is that it is too simple. However, the HSB-No. 1 computer can readily digest much information from such a study if it is standardized and replicated enough times. (The HSB-No. 1 computer is the *Homo sapiens* brain that *thinks*.)

Studies that are too localized do present difficulties when we try to learn and discover ecological processes. This is particularly true in fire ecology. Some studies remind me of an intensive investigation being made of a

carburetor without any knowledge of the auto. This kind of study certainly makes it difficult, if not impossible, for the investigator to relate the carburetor to the process of propulsion, let alone acceleration, starting, and ignition.

Lightning storms.—I believe it is pertinent to discuss the thunderstorm in some detail, for this natural mechanism is not just a local phenomenon. The electrical discharges during thunderstorms have been considered by several investigators to be a mechanism to assist in maintaining the balance of the earth's electrical field (15, 17, 19, 20, 29, 36). The electrical field surrounding the earth is important ecologically, although in many respects still unknown particularly in regard to its effect on living organisms.

All living organisms depend upon electrical processes essential to life. Every single living cell is an electrical battery with a positive and a negative charge. If the cell membrane is ruptured, the electrical potential of the cell is discharged and the cell is no longer alive. Life, through chemical processes, is electrical and is carried on in a medium that is also electrical--the electric field. Ecologists and physiologists have long overlooked this vital aspect and the role played by it in our atmosphere and climate. Surely, the electrical field and electricity are as necessary to living things as are the other more easily studied physical effects of the atmosphere and climate. Unfortunately, electrical effects on living organisms are virtually unstudied. However, electricity during the thunderstorm has been investigated, but there is still much to be learned.

The thunderstorm is extremely important to us in this symposium not only because of lightning-started forest fires today, but also because of fires ignited long before man had evolved. In a study of nature, one of the first prerequisites is to attempt to discover and understand the interrelationships of plants and animals and their environment before these were manipulated by man.

Fire is a natural environmental force, and it is particularly important to learn what natural processes are involved because these usually cannot be altered materially by man. Thunderstorms were, and are, a part of our environment. Their frequency patterns have changed and will continue to change as do other more easily observed climatic changes. Certainly, something that is as involved in the electrical balance of the earth's charge, as are thunderstorms, is of considerable biological importance.

Schonland (29) wrote that the different electrical discharges on earth have been recognized for about 100 years but that, until rather recently, "no acceptable explanation could be offered for them," and that there had to be "some charging process *continually* at work." Also:

... there are some 40,000 thunder-clouds in action over the whole world every day and each of these acts as an *electrical generator* floating between the earth and sky pumping electricity from one to the other, and so maintaining negative and positive charges on earth and upper air respectively in spite of contrary leakage cur-

rent flowing in fine-weather regions. (*Italics mine.*)

Schonland (29) also emphasizes that because the earth is electrified, "... One of its rather striking consequences is that the charge in fine-weather regions should fluctuate with the total thunderstorm activity of the world."

I hope this very brief and generalized explanation has impressed upon you that lightning, and the resulting thunderstorm, is one of the primary forces on earth and that this activity was here from the beginning of the earth. It is likely that life itself was formed by the action of lightning (26, 35).

Lightning and fire ecology.—Now, what evidence do we have that lightning does indeed ignite fires in nature, particularly in the northern environment? Fortunately, data have accumulated from many parts of the world including Alaska; so today there can be no question that lightning has been, and is, an important ecological factor (15, 16, 17,). Although many writers have mentioned lightning fires, usually very cursorily and briefly, in Canada and Alaska it has been only relatively recently that quantitative and qualitative data have been available. These have been brought together in excellent fashion by foresters, not ecologists in the usually biological sense. This discipline, the science and profession of forestry, has made a tremendous, although as yet unrecognized, contribution to this field.

Some of the very valuable papers about the northern environment should be intensively studied by all that are interested in the ecology of the Alaskan environment. For example, in 1960 Bennett published his "Survey of Lightning Fire Occurrences in Canada's Forests—1950-1959" (2), in which he plotted nearly 10,000 lightning fires from Newfoundland to British Columbia. In 1963, Hardy and Franks (11) reported extensively on both lightning- (746) and man-caused (2,672) fires primarily in interior Alaska. Requa (28) wrote on the lightning fire patterns in "Lightning behavior in the Yukon." Recently, Barney (1) reported an extensive study on "Interior Alaska Wildfires 1956-1965." All of these investigators are ecologists as well as foresters.

Their findings show a high incidence of fires in the northern environment, except for the far northern barren-ground type of tundra. There appear to be no records of lightning fires north of the Brooks Range in Alaska and in the far northern reaches of Canada. Some meteorological evidence, which we do not have time to discuss here, indicates lightning may be very infrequent or, for long periods, not at all possible there. Because of time limits, we will discuss primarily the interior of Alaska as delineated by Hardy and Franks (11) and Barney (1).

From their investigations, we learn that in the period 1950-58, 546 or 24 percent of the recorded fires were by lightning, and these accounted for 76 percent of the burned-over acreage (11). And in the period from 1956 to 1965, 834 or 38 percent of the recorded fires were lightning caused and accounted for 97 percent of the burned-over acreage (1). They agree on

1957 as the peak year for lightning fires and that the lightning fire season is from mid-May to September 1, whereas the man-caused fire season is from March into October. The percentage of lightning fires, however, varied from 62 percent in 1959 to a low of 20 percent in 1965.

Hardy and Franks (11) published an interesting map of lightning fire occurrence by isograms which shows that nearly all the fires occur in the continental and transition climatological zones of Alaska. They point out, however:

If complete detection coverage were possible, the lightning fire isogram might appear considerably different. Over the past many years, detection and reporting have been almost entirely by such volunteers as airplane pilots, travelers, local residents, and miners. We now know that many lightning fires occur in areas for which the isogram indicates a low frequency. Some of these fires burn large areas, and some may combine with other fires and appear as only one for reporting purposes. Others burn and die out without being reported. Many fires do not spread beyond a very small size, and their existence is never known. Better detection and better reporting methods will no doubt change the pattern of the lightning fire isogram during the next few years.

Although man has been in Alaska only a relatively short time, he has made some rather drastic changes in the environment, but he certainly has not changed any basic ecological principles. He may have changed the effects of these, accelerated them, or slowed them down; but they still continue.

The importance of lightning fires in interior Alaska is only too well known to those who have to fight such fires. Unfortunately, this is not known by either biological investigators or the general public.

Nature of fire.—Let us examine this process we call fire more closely, keeping these basic ecological “laws” in mind with the keen appreciation that there is more there than meets the eye.

The flame and heat that we see from burning material, not only produces light, but many other various radiations in many wavelengths. Unfortunately, little is known about most of these, except perhaps infrared, and still less is known of their relationship to living things. However, we do have evidence that some of these wavelengths are indeed important at least to certain animals. Evans (8) has reported in detail about his investigations of the fire beetles, a species of the genus *Melanophila*, and the infrared sensory pits on their hind legs. These remarkable insects can detect and locate forest fires over long distances. They are attracted to the burning forest, and the fire apparently triggers such reproductive processes as courtship and mating. This was first observed by Poulton (27) in 1915, and recent studies have proven their connections with infrared sensing organisms. These beetles are found in Europe, Asia, United States, Canada, Mexico, and one species in Central America. In North America, all 20 species are most abundant in the

southern part, with two species in Alaska.

The relationships of animal behavior to fire is a fertile, pioneer field for research. I have recently reviewed some of the interesting aspects of such studies in "Fire and Animal Behavior" (21). Callahan (6, 7) has discussed the many possible and fundamental relationships of such animals as insects to various electrical wavelengths. He has also shown that they have many different organs to detect some of these and points out that there must be many other unknown radiations. One cannot even conjecture as to the many possible electrical radiations and phenomena that may be a vital part of our atmosphere and climate.

We, like many other animals, feel some of these rays as heat. These are so familiar that at times we do not relate some very obvious characteristics of these to our studies and problems with fire. The fact that the greatest amount of heat is above the burning material, not below it, is often forgotten. We all know and practice this knowledge, that nearly all the heat is greatest at the "cone" of the flame and that little is below the source. In fact, the differences in temperature between the heat at the "cone" level in relation to that below it are so great that the latter appear to be insignificant. Wherever studies have been made, the soil is such a good insulator that very little heat reaches below the surface levels, except when exceedingly heavy accumulations of fuel develop and are ignited. Most of these types of fuel accumulations are caused by man, and there is little relation of these to either natural fires or controlled burning except in certain very exceptional instances. For example, the wildfire that occurs following clearcutting timber operations is certainly not comparable in most respects to a natural fire.

Fire and plants.—Certain vegetations have evolved interesting adaptations to the intense heat above the fire. Many species of pines, as well as some other conifers, in many parts of the world have serotinous cones that require heat to release the seed. Fowells (10) writes in relation to the jack pine (*Pinus banksiana*) that:

Heat from a heavy slash fire, with temperatures recorded at 1400 degrees at 1 foot above the ground to 600 degrees at 17 feet, is sufficient to open all cones on a tree. The seeds in the cones are uninjured by temperatures that do not cause actual cone ignition, which is 60 seconds at 700 degrees to 2 seconds at 1300 degrees. Cones exposed to temperatures of 900 degrees for 30 seconds had high seed viability but those exposed for 60 seconds did not.

In the Alaskan environment, the black spruce (*Picea mariana*) has the serotinous cone habit in varying degrees, and the cones can be blackened by fire and still remain sound. The sand pine (*Pinus clausa*) that grows on certain sterile white sand ridges along the Gulf of Mexico coast in northern Florida also has serotinous cones and likewise the lodgepole pine (*Pinus contorta*) of the northern environment.

Another adaptation, generally recognized by foresters, is that many forest

tree species in Alaska require mineral soil for best germination, seedling survival, and growth. The two major species of conifers, black spruce (*Picea mariana*) and white spruce (*Picea glauca*), have established forests on burned-over land the breadth of a continent in its widest section. It should be said, however, that repeated burning of these same forests will eliminate seed trees and eventually the forest. We have, however, focused too much of our attention in the past only on the trees. Trees are but a part, and in some regions a very small part, of a rather complicated system of living things, plants and animals, as well as minerals, water, and climate. The forest should be considered, even if it is of the greatest economic importance in many regions, as only part of a system, not the system itself.

Many plant species respond to fire and its effects in many other ways, too many to begin to enumerate here. Many seeds of plants germinate more readily and rapidly if slightly heated or burned, many others produce seed profusely on mineral soil. Fire must be recycled in the environment if these species are to exist in any numbers. One of the most spectacular sights in the north is the reaction of the fireweed (*Epilobium* sp.) which, at times, covers entire burned-over mountainsides here in the northland. A similar phenomenon with many other species of plants takes place in many parts of the world and for this reason, such plants are called "fireweeds" by local people.

There are also plant relationships to the smoke from fires. One such example is the effect of the gas, ethylene, a component of wood smoke, on initiating flowering. A common custom in Puerto Rico in the past was to flood the pineapple fields with wood smoke to initiate even flowering and thus a uniform harvest. Today, this is more easily accomplished by the use of ethylene gas.

When a fresh burn is examined, the most obvious thing we see is the ash, the quantity depending upon the amount and kind of fuel burned and under what conditions of moisture, humidity, and wind the fire occurred. The ash, however, is always high in calcium, potassium, phosphorous, and other mineral elements. These are the chemical elements that have been released from the organic matter in a usable soluble form and utilized by both plants and animals. The recycling of these nutrients is of the utmost importance here in the Alaskan environment where other processes of decay, oxidation, and recycling of minerals is slow.

The effects of fires on plant succession are perhaps the simplest to study; but even here, because of the variability of fire, the results can be quite frustrating to the investigator. Perhaps one reason fire ecology has been so late to come of age is the fact that not many studies can be conducted and completed in 2 or 3 years, particularly in the northern environment. Plant succession as related to certain forest tree species has been studied probably more than any other ecological aspect. We certainly lack information on most other vegetations as well as the relationship of animals to these successional changes, particularly in interior Alaska.

Succession of plants, however, is one of the most studied aspects of fire

ecology, and it is not necessary to use refined and highly technical methods to find out at least general processes. A surprising amount of information can be obtained simply by establishing a permanent reference point such as a concrete post and photographing the area around it before, during, and after the fire from time to time throughout the year and from year to year. Color, black and white, and infrared photos, if taken regularly over a period of time, will yield much interesting information.

Fire and soil.—The effect of fire on soils has been and is quite controversial for several reasons. Perhaps the foremost of these is the fact that soil science, like forestry, developed and was nurtured in a unique environment—the hardwood forests of Europe. It is not generally recognized that the deciduous hardwood forests of the world are rather unique areas when looked upon as part of the earth's biosphere. In area, they represent a very small portion of the vegetative covering of the earth, yet the methods, ideas, and philosophies developed there have been applied literally everywhere, exactly as was the idea that all fire was bad. It is time for ecologists, particularly, to reexamine soil ecology in relation to the major aspects of the globe and not some small unique area of the earth where man just happened to develop such ideas. The most fertile, at least for man's use, are the natural grassland soils of North America and similar regions elsewhere, not soils that were once covered by a deciduous forest.

Because of this, I believe our present methods of study and analysis of soils leave much to be desired. It is extremely difficult in a practical way to depend upon soil analysis for agriculture. Soils that produce a good crop of corn may show poor soil fertility and vice versa. In connection with studies for heat and drought resistance in hybrid corn, I was able to conduct research experiments with the Pueblo tribes of the Southwest and in particular with the Hopi. Soil analysis by both government and private testing laboratories showed not enough nitrogen to produce any corn, yet consistently these same fields were producing satisfactory yields for that particular location. Nitrogen differences or lack of it have been part of the confusion on burned versus unburned soils. However, it is evident to anyone who has looked upon burned-over grassland that the resulting growth on the burn is much darker green in color as if some quickly available form of nitrogen had been applied. This I have found to be true, not only in many parts of North America but in Africa and Australia as well; it is a universal principle. Lutz (25) has also commented on this nitrogen effect with somewhat the same results in Alaska. This effect is certainly recognized by animals universally, because both wild and domestic animals will seek out burned areas.

Wherever this growth has been analyzed, North America, Africa, Australia, and South America, the results have always shown the vegetation has a high protein content as well as potassium and phosphate (14, 16, 21). Burton (5) in studies of highly improved coastal bermuda (*Cynodon dactylon*) pastures in the South, has reported that such pastures will produce 1 ton more of hay per acre if burned over properly and that the effect on protein value appears

to be equivalent to a considerable application of nitrogen fertilizer. He has suggested that the underlying reason may be the stimulation from and rapid effect of the high calcium, potassium, phosphate, etc., ash on the nitrifying bacteria in the soil. If this is so, fire may indeed have an important place in the ecology of Alaskan soils.

The effect of the higher temperatures on the burned, blackened soil could also have some important ecological action on the development of nitrifying bacteria and other similar organisms, particularly with the long summer days in the interior of Alaska. Certainly, the effect of fires on the permafrost, the temperature of the soil, and other similar aspects would be a fruitful field of fire ecology research. Processes taking place during 20 to 24 hours of solar radiation might be quite different than elsewhere.

Fire and animals.—The change that fire produces in plant communities has a long-reaching influence on the animal occupants, for plants are the foundation of all animals and animal communities. The variability of fire, the variability of fire impact on plants, and the variability caused by the incomplete burning processes create an intensive and extensive diversity of plants. These plant communities are inhabited quickly by a large variety of animal species. Fire creates more variations in both plant and animal communities than probably any other natural force.

The variations of fire, by its intensity and frequency, determine, for example, whether the range will be occupied by moose or caribou in much of the boreal forest regions. When the first Europeans came into the North, caribou were found as far south as Maine and Minnesota. The fire relationships of the numerous large mammal herds of east and southern Africa are very important. Most of these animals are either grazers (grass, forbs, sedges, etc.) or browsers (bushes). The relative proportion of these mammals compared with forest animals is determined largely by the amount, intensity, and frequency of fire (22a). Recently, I have reviewed the place of fire in the management of wildlife habitat in the southeastern States (22).

Speakers of many of the 149 papers presented at the first 10 Tall Timbers Fire Ecology Conferences stressed the importance of fire in the management of animal life in many parts of the world including the boreal north. I have also discussed the place of fire in the lives of animals from insects to mammals in recent years (see "Literature Cited").

In interior Alaska, much more intensive and long-term study of fire and its relationships to the animal life is needed (such as Skoog's (31) dissertation on the caribou in this region). Many of his findings are quite different from those of others, such as Scotter (30), in the far northern tundra of Canada. Long-term studies should be initiated at the Kenai Wildlife Refuge, particularly on moose, instead of studying the effects of wildfire after long periods of fire exclusion.

When a uniform blanket of highly flammable fuel is allowed to develop and then catches afire, we are witnessing a phenomenon created by man, not

a natural one. The excellent studies at Kenai (32) show a striking increase in moose populations following severe wildfire. Must we always wait for disastrous wildfire under unnatural conditions created by man to recycle moose populations? The Kenai moose is a distinct form, the largest of the species, and must have been an inhabitant of the Kenai Peninsula a long time. Proper management needs to be practiced in place of dependence on extensive wildfires.

Interior Alaska is a vast breeding ground for many species of waterfowl for the North American continent. Many questions such as the following need answers: Will fire exclusion eliminate waterfowl breeding grounds by natural succession from open grass or sedge areas to bush, or even to muskeg? Will fire exclusion eliminate waterfowl food plants and resting grounds? It is my belief that lightning fires in the past have played a great part in recycling plant succession in this region, but long-term studies are needed before any fire exclusion policies are decided upon.

Fire in Alaska

Fire before man.—Interior Alaska, in its pristine condition before the coming of man, was a mosaic of plant and animal communities caused by temperature, moisture, topography, soils, and those many other climatic and environmental aspects that can influence plants and animals. Superimposed on this pattern was another mosaic caused or created by lightning fires. This mixture of plants and animals varied from time to time because of changing climatic conditions. Likewise, the numbers, intensities, etc., of lightning fires must have varied also, and there might have been a possible periodicity of such fires as we have now in temperature and precipitation (19, 20). Interior Alaska is a lightning fire region today and must have been for a long time in the past (16).

Fire and early man.—When the first men entered Alaska from Asia they were already familiar with fire. Some of the earliest archeological evidence on early man (*Homo erectus pekiensis*) and fire comes from ancient caves with hearths near Peking, China (3). The early Alaskan people must have used fire for such purposes as heating, attracting game, preparation of food and easier travel. These people by such use changed this original lightning fire mosaic to some extent. However, they were few in number and interior Alaska is large in area so their effect was probably not too extensive.

Now I do not believe that these people or later the Eskimos and Indians were necessarily careless with the use of fire. The forestry profession has by repetition convinced many people, including even anthropologists and botanists, that they were careless because early European pioneers were. Until modern times, forests had little to offer for human sustenance. These so-called primitive people lived in a fire environment (16, 18); and if they had not been reasonably careful, they would have suffered—extinction by a process of natural selection would have occurred. These people had a

knowledge of fire use and management that has been long lost to modern man.

Native tribes in many parts of the world even today where their culture has not been destroyed show a remarkable skill in the proper use of fire for their particular purpose. Time will allow me to mention only two such examples. One of the problems of poaching in some of the east African national parks is caused by local tribesmen burning small areas in which to set their snares when the green grass "flushes" and attracts game because of its protein content and tenderness. I have seen such areas burned out, only 4 or 5 acres in size, in grasslands where the grass is from 6 to 8 feet tall, without the use of any firebreaks. They can do this only because of an innate knowledge and experience in the use and nature of grass fires. Such "snare" areas were seen along the boundaries of Murchison Falls National Park, and such methods are apparently common in many regions where the local culture has not been destroyed by more modern cultures. The Masai in east Africa show a remarkable knowledge in regard to burning for their cattle's needs. When they allow fires to burn into forests, it is because the forest is of no value to them, because cows cannot eat trees.

Fire, Eskimos, and Indians.—Unfortunately, the natives' uses of fire, except for heating and cooking purposes in Alaska, have not been recorded to my knowledge. They knew that certain animals would be attracted by green burns, and I believe they used fire for this purpose.

The forestry profession has made man realize the importance of wood products in modern civilization to such an extent that man has forgotten that he is a grassland animal, not a forest animal. For this reason, I digress to point out that even today, in spite of our technological culture, we remain grassland animals. Our "bread" comes from cereals which are grasses, and present studies indicate that they were developed from fire-adapted grasses (18). The "meat" in our diet comes largely from animals that eat grass, forbs, or shrubs and cannot in any manner be considered forest animals. Nearly all, if not all, of the major cereal food plants and our major domestic livestock apparently came from fire environments. Our civilization is founded on grains and animals that were developed from the wild by so-called primitive people and given to us essentially as they are today; we have simply increased yields and have yet to domesticate a major food product, either cereal or meat. It is my belief that people who could develop such food products also had a real fundamental knowledge of fire ecology. They must have mastered the art of fire management to a great degree, because their life and livelihood depended upon such skill.

However, as with the earlier peoples, the numbers of Eskimos and Indians in interior Alaska were not great in proportion to the size of the land area, so their fires had little permanent effect on the natural fire mosaic created by lightning.

Fire and the European.—Probably the greatest change of all occurred with

the beginning of the gold rush, for in their need for wood for various purposes, miners literally stripped the mountainsides of timber. In addition, many were careless with their fires and probably burned mountainsides on purpose to make easier access for prospecting. Requa (28) has written:

... Old timers have told me that at the height of the Rush, there were continuous fires burning along the entire length of the Gold Rush route. The paddle-wheel river boats devoured firewood at a tremendous rate and at the crest of the steamboat era, it is estimated that 300,000 cords of firewood were burned each summer.

The rock-hard permafrost of the gold placer ground was thawed with wood fires. The thawing was later carried out with wood-fired boilers and the gold recovered with wood-fired dredges. Consequently, nearly all available firewood within 40 miles of the gold field was utilized.

The amount of timber that has been cut for firewood, as well as for other purposes in more settled parts of Alaska, must be large. Zivnaska (37) has estimated that in the conterminous 48 States the present cutting of wood-pulp is only about equal to that cut for firewood, etc., less than 75 years ago. Along with the cutting of timber in Alaska, man leaves more accumulation of fuel such as slash and other debris on the ground than would occur naturally. Fires, man-caused and lightning-ignited, have burned and reburned some regions repeatedly. In some areas, man has been burning at a much more frequent rate than would occur naturally. Hardy and Franks (11) and Barney (1) show that the peak in numbers of the man-caused fires occur earlier in the year than that of lightning strikes. This earlier burning may cause different effects than later burns. They also show that man-caused fires occur later in the year as well.

Fire Management in Alaska

Fire control versus fire management.—Fire control consists primarily of firefighting techniques, firefighting equipment, and the necessity to get to the fire quickly so as to suppress it. Forest fire control literature consists largely of such data as the rate of spread and the conditions under which fires can or cannot be extinguished. There has been an obvious lack of interest in fire prevention by reducing hazards or flammable conditions in Alaska. The effort in this field has been toward making people aware of fire danger so as not to be careless with materials that will ignite fires. Fire management is much more than fire control. It includes fire prevention—measures to be taken to lessen fire risk—as well as an understanding of fire ecology. City fire departments take great care that undue accumulations of hazardous substances do not occur, and urban areas have strict regulations in this regard. Forest fire control agencies usually pay little attention to the accumulation of flammable materials. This certainly cannot be construed as fire management. In any management program, whether it be for forest, field, or urban development, goals must be set. The goal for fire management

should be stated for various conditions, vegetations, and purposes and not only the usual fire control goal of "allowable burn" except in instances where fire exclusion is necessary.

Forest fire management.—Now just what do I mean by such a program. First must come a planning stage for the interior based on the various needs or requirements for Alaska. A growing State and economy certainly need forest products. The most valuable forests in Alaska are the black spruce and white spruce which are fire adapted trees, but unfortunately are adapted to catastrophic fires primarily for regeneration purposes. The forest is vulnerable except to the lightest of fires.

Hardy and Franks (11) reported that, of the approximately 300 million acres of Bureau of Land Management-administered land in interior Alaska, only 120 million acres or slightly more than a third can be considered forest land and that, at present, only some 40 million acres can be considered of commercial quality. That means only about 33 percent of the total forest acreage is an economic forest and only about 10 percent is presently accessible economically. Thus, the greatest priority for both fire management as well as for forest management should be given to the 4 million acres of accessible timber.

To utilize forests for commercial production, we must keep fire out until after the timber operation. These forests are usually clearcut, and slash fire or burning takes the place of the natural catastrophic fire by lightning. However, we must also recognize that a uniform or monoculture forest over vast areas is not a natural one. The development of continuous forests of highly flammable material creates hazardous conditions over vast areas. Measures should be introduced into forest management that will not allow uniform fuel conditions to develop over large regions. This can be accomplished up to a certain degree by smaller and well-distributed clearcuts so as to maintain an overall condition of different kinds of fuel. In this way, the former natural lightning-fire mosaic can, to a certain degree, be recreated.

Urban fire management.—Probably of even greater importance to the public are the areas around cities and towns. As the population increases, more and more people will be living in the midst of Alaska's fire environment. In such areas, methods should be developed to lessen the risk of fire by various methods of prevention. City fire departments have rather rigid rules about storing or allowing flammable materials to develop around habitations. I have noted that the Fairbanks Fire Department has used controlled burning to burn down old houses that are great fire risks, and the Fairbanks *Daily Miner* captions such fires as "controlled burns." In many regions, measures are taken to reduce the flammable vegetations to the lowest denominator or of the lowest fire risk such as grass. The Florida Forest Service has initiated a very successful procedure in this respect. They have organized volunteer fire departments in the various small towns and teach them to control-burn vacant lots or areas of fire risk at a time when

the conditions are right for a cool or feeble fire. This has lowered the incidence of wildfires around towns in north Florida considerably and in doing so also has made many areas less dangerous and more pleasant to live in. I cannot see why such a procedure would not work in Alaska. Training and paying volunteers to control-burn would furnish employment and lessen the cost of fighting large fires.

Fire management for wildlife, watershed, and recreation.—Well over 200 million acres in the interior of Alaska consist of nonforest or uneconomic forest lands but have a great potential for wildlife and recreation. These are also valuable because they represent a large area of watershed. I have already discussed the reasons for considering this a natural lightning fire region, and further investigation may prove it to be even more so. Thus, the wildlife, including both game and fish, must be well adapted to such a fire environment. Man's efforts should be toward maintaining this habitat in as natural a condition as is humanly possible. Much of the area represents a very unique terrain for it is underlain with permafrost, essentially a mixture of frozen soil and ice. It is a very special kind of environment and extremely fragile to human interference. It is a natural lightning fire environment. Thus, any great change or disturbance in the fire pattern may have far-reaching consequences. Unfortunately, the fire ecology of this region, in spite of the fact that it is a vast breeding ground for much valuable wildlife, has been virtually unstudied. Likewise, the effect these natural fires have on the maintenance of the fertility of the rivers and lakes has not been investigated. The relationship of fire to the vegetation and this in turn to the protection and maintenance of the permafrost conditions has been only cursorily studied. No rational fire management plan can be proposed for this vast area because of a great lack of ecological information. How much burning, over-burning, or fire exclusion this permafrost region can tolerate without damage remains to be learned. Investigations should be made on what wildfires are doing, and experiments should be started to study the longtime effects of fires of different frequencies, intensities, and kinds on the vegetations and wildlife, and on the permafrost conditions as well. At our present state of knowledge of this vast region, the lightning fires should be allowed to burn unattended except in regions hazardous to human endeavors or prime forest stands. Fortunately, both of these latter conditions are usually along the rivers, and it might be possible in some instances to create buffer strips by controlled burning.

Controlled or prescribed burning, although quite widely used today in many parts of North America, Africa, and Australia, appears to be quite unknown in Alaska. In Australia, large areas are burned annually by aerial ignition, and these techniques have become very refined and particularly useful in regions accessible only by aircraft. Large areas, up to 100 square miles in one burn, are burned in Kruger National Park in South Africa by the use of widely spaced firelines. Much of the permafrost region of interior Alaska is ideally adapted to burning by aerial ignition, either by plane or by

helicopter. Such controlled burning in many sections of Alaska could lessen the danger from large uncontrolled fires to human habitations or economic forest lands. I would certainly suggest that attempts be made to study and use prescribed or controlled burning in such areas in the interior where management decisions would dictate such protection instead of relying entirely on fire suppression.

Summary

I have discussed the basic principles of fire ecology. These are principles because the various effects are produced in like manner around the earth where there is fuel that will burn. I have tried to point out that interior Alaska is a lightning fire region. Fire ecology research in the Alaskan environment is virtually unknown. In those areas in the interior where lightning fires are quite frequent and where in addition there are man-caused fires, fire ecology research should have topmost priority. As the human population increases, more problems will develop because interior Alaska is a fire environment. Knowledge of the relationship of fire to forests, grasslands, bogs, soils, lakes, and rivers in Alaska is needed if we are to manage wisely.

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Fire in the Northern Environment



Erosion, soil properties, and revegetation following a severe burn in the Colorado Rockies

Abstract

During the summer of 1967, 20 erosion plots, 42 soil sampling points, and 50 vegetation plots were established in the Comanche Burn area, a 470-acre burn in the Central Rocky Mountains. Observations indicate that erosion during the first summer after the burn was not a serious problem but that some erosion was occurring. The amount of rock exposed on the soil surface is more important than slope in initiating particle movement during low intensity storms but slope is the controlling factor during high intensity storms. Analysis of soil physical factors show that the burn had very little effect in spite of a complete destruction of litter and surface vegetation. This was attributed to the coarse textured soils.

Revegetation after the burn showed a steady increase with an average of 3.5 spruce-fir seedlings the first year and 22.4 seedlings per acre the third year. Lodgepole pine seedlings increased from 1,185 to 1,385 seedlings per acre over the 3-year period, and aspen suckers increased from 686 to 24,000 per acre over the 3-year period. Subordinate vegetation also increased in number and species composition.

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Introduction

Wildfire on a watershed is generally a cause for alarm to the resource manager. Of the many potential disturbances to a watershed, fire is one of the most severe. Many studies have reported the detrimental effects of forest denudation by fire. In addition to the economic loss of the timber, increased flooding, increased erosion from the bare slopes, increased sediment loads in the streams, slope failures or land slumps, and great debris flows have been documented and studied in detail in many parts of the country.

More recently, fire has been recognized as playing an important ecological role in maintaining the species compositions of many forest types. Aspen and jack pine in the Lake States, longleaf pine in the South, ponderosa pine

in the Southwest, and lodgepole pine in the Rocky Mountains are just a few of the species whose natural regeneration and survival are related to periodic fires.

Although naturally occurring fires apparently are advantageous to some species, it seems likely that they are equally harmful to others, particularly those types existing in harsh environments where the development of any vegetative cover is a slow process. Examples of these environments would include the northern environment, where the length of the growing season limits growth, and arid and semiarid environments, where lack of moisture limits growth. In these areas as well as many forested areas, damage by fire to the watershed is generally of more concern than any ecological benefit which may occur.

This paper examines the effects of a severe burn in the Colorado Rockies. The effects of the fire upon soil erosion, soil properties, water quality, and the establishment of vegetation following the burn are presented. The data presented are based upon the work of Delp,¹ Kilinc,² Meyers,³ and Barth,⁴ to whom the authors express their deep appreciation.

The Comanche Burn

On August 29, 1966, at 1:30 p.m., a slash disposal fire burning in the bottom of the empty Comanche Reservoir spread into the adjacent forest as a result of sudden gusts of wind. By 3:00 p.m., the fire crowned and spread rapidly upslope. Two days later, on August 31, at 10:00 a.m., the fire was under control although it was not declared out until September 29. During the 2 days of uncontrolled burning, 470 acres of lodgepole pine and spruce-fir forest, containing over 3 million board feet of timber, were destroyed. The fire was complete, killing all the aboveground vegetation within its boundaries. The fire was hottest in the lodgepole forest. Here, most of the branches were burned off the trees, and the litter and duff layers were completely consumed, leaving a deep layer of ash and bare mineral soil. The fire was less intense in the spruce-fir forest. Although all the trees were killed, branches remained on the trees, and in many locations, a layer of charred duff was present on the surface. The upper margin of the fire coincided in places with the boundary between the spruce-fir forest and alpine tundra. Here the fire generally died out because of the lack of fuels in the tundra.

The burn area is typical of much of the Colorado spruce-fir, lodgepole pine country. The topography is mountainous with numerous rock outcrops

¹Phil G. Delp. *Soil movement following an intense burn*. M.S. thesis, Colo. State Univ., 91 p., 1968.

²Mustafa Y. Kilinc. *The effect of wildfire on soil properties*. M.S. thesis, Colo. State Univ., 100 p., 1968.

³Alan E. Meyers. *Mountain water pollution from road reconstruction and wildfire*. M.S. thesis, Colo. State Univ., 70 p., 1968.

⁴Richard C. Barth. *Revegetation after a subalpine wildfire*. M.S. thesis, Colo. State Univ., 142 p., 1970.

and talus slopes. Within the burn areas, steep slopes prevail with maximum slopes up to 70 percent. However, there are several small areas of essentially level terrain including alluvial bottoms along streams, and several upland areas. Elevations range from about 9,300 feet at the reservoir to over 10,600 feet at the upper end with a mean of 10,000 feet.

The climate of the area is continental with cool summers and severe winters. The mean annual temperature averages about 35° F. Precipitation occurs primarily as snow between October and April. Strong downvalley winds limit snowpack development to forested or other sheltered areas.

Soils within the burn area are primarily of the Gray Wooded and Podzol great soil groups with small areas of alluvial sands and gravels near the stream bottoms and colluvial deposits along the lower slopes. Surface soils over the area are generally sandy loams with a high proportion of rock both at the surface and within the profile.

The vegetation of the burn area was about equally divided between the lodgepole pine type (*Pinus contorta*) and spruce-fir type (*Picea engelmannii-Abies lasiocarpa*) with the lodgepole pine predominant on the lower eastern side of the burn and the spruce-fir occupying the upper western side of the burn. A clear demarcation between types did not occur but rather an intergrading of species of both types. Small patches of aspen (*Populus tremuloides*) occurred throughout the burn. The lodgepole type averaged about 110 square feet of basal area with 1,600 stems per acre. The spruce-fir type had an average basal area of about 150 square feet and about 900 stems per acre. Based on measurements in adjacent forest stands, litter and duff accumulation ranged from 10.8 to 48.3 tons per acre with an average of 20.4 tons per acre.

Because of the fire's proximity to a water supply reservoir, there was immediate concern that erosion might pose a problem, and revegetation measures were undertaken. On September 3, 1,500 pounds of grass seed were dropped by helicopter on the burn area. Because of high winds and turbulence caused by the helicopter, the seeding was spotty with most of the seed landing in the lower portion of the burn.

In the summer of 1967, the first growing season after the burn, a comprehensive study was begun to accomplish the following objectives:

1. To determine the extent of erosion and soil movement within the burn area.
2. To determine the effect of the fire upon the hydrologic characteristics of the soil including relative infiltration rates and some chemical and physical soil characteristics.
3. To determine the effect on water quality of streams passing through the burn.
4. To determine the pattern of vegetation establishment on a series of permanent sample plots over a number of years.

EROSION

Since the fire occurred at the end of the summer of 1966, only light rainfall occurred prior to the winter snows. An inspection of the area in December 1966 revealed no evident erosion within the burn and a layer of ash over most of the area. By June of 1967, the ash layer had been either compacted by the snowpack in the sheltered areas or blown off by the winter winds in the exposed sites. At the beginning of summer, the burn area was essentially a bare soil-bare rock surface with no sign of live vegetation.

Twenty erosion sampling plots were located on aerial photography and then on the ground (fig. 1). Plots were generally located along slope transects so as to have plots at various slope positions. Plots on slopes were located on the upper one-third of a slope, the middle one-third, and at the base. The percent slope and percent of surface rock were recorded at each plot. A 6-foot transect on a line perpendicular to the slope was established at each plot to serve as a reference for soil particle displacement. Soil particles along each transect were tagged with either an isotope (CS-134) or a fluorescent dye. Soil particle movement downslope was measured after each storm. In addition, changes in microrelief along the transects were measured as an index of soil loss over the measurement period. Soil particle displacement and soil losses were related to the amount of precipitation, the maximum 30-minute intensity, the percent of rock cover immediately upslope from the tagged point on the transect, the slope percent, and the area of any upslope obstructions.

Precipitation during the summer months was very close to normal with 2.24 inches in June, 2.48 inches in July, and 2.81 inches in August. The largest storm of the summer was on June 28 when 0.70 inch fell with a

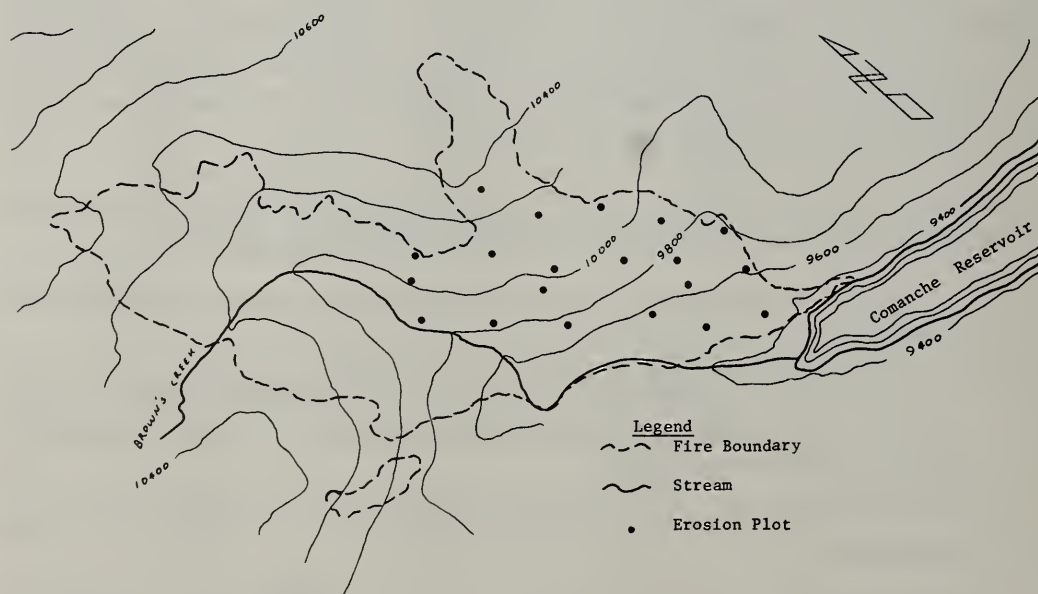


Figure 1.—Distribution of erosion sampling plots, Comanche Burn.

maximum 30-minute intensity of 0.22 inch per hour. The second largest storm occurred August 28 when 0.40 inch fell with a maximum 30-minute intensity of 0.43 inch per hour. Soil particle movement on the slope was directly related to slope percent, the percent of rock cover, and the maximum 30-minute intensity of precipitation. The maximum soil movement measured was 25 feet on a 62-percent slope. Soil particle movement by raindrop splash action, as measured around dye spots on level ground, averaged about 5 feet over the summer. Total soil loss from the slopes averaged about 0.25 inch.

In general, soil loss from the burn area was very small. Although local erosion was frequently observed, especially where surface drainage networks became established, most eroded particles were redeposited downslope as the slope gradient flattened or behind obstructions such as logs or rocks. Large particle movement was also observed on steep slopes where rocks became dislodged and rolled down the slope. It is evident that the lack of intense storms and the coarse texture of the soil were the major factors restricting erosion.

SOIL PROPERTIES

Fire is generally considered to have a deleterious effect upon forest soils. A closer examination of the literature reveals that this is only true under some conditions. In general, fire affects the soil if the fire is severe. Infiltration rates, organic matter contents, and porosity decrease, but bulk densities increase. This effect is more pronounced on fine textured soils. Light burns frequently have little or no effect on these same properties.

In the Comanche burn, 42 sampling points were established along five transects traversing the burn (fig. 2). Of these 42 points, 26 were in the burn

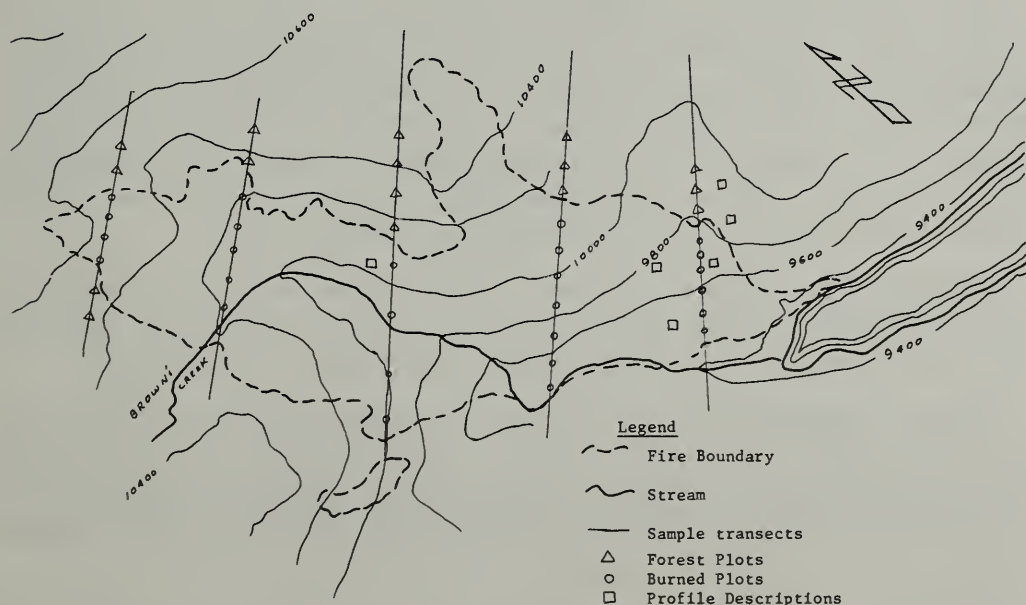


Figure 2.—Distribution of sampling points for infiltration and soil properties.

area and 16 in the adjacent unburned forest. Measurements taken at each point include infiltration rate, bulk density, the depth of ash or litter, percent of surface rock, basal area, slope, and aspect. In addition, samples were taken for laboratory analysis of organic content and texture. In the unburned forest, litter samples were taken to determine weight. Calcium, pH, phosphorus, nitrogen, and potassium were analyzed for just a few burned and unburned samples. Results of the soil tests are given in table 1.

TABLE 1.—Average burned versus unburned soil characteristics

Variable	Burned	Unburned
Average 60-minute infiltration rate (inches per hour)	12.1	10.2
Final infiltration rate (inches per hour)	9.5	8.0
Organic matter content (percent)	1.0	2.6
Bulk density (grams per cubic centimeter)	1.1	1.2
pH	5.0	5.1
Calcium (p.p.m. ¹)	525.0	1367.3
Phosphorus (p.p.m.)	13.7	23.0
Nitrogen (p.p.m.)	1.4	.6
Potassium (p.p.m.)	123.6	200.0

¹Parts per million.

Infiltration rates were somewhat greater on the burned plots than on the unburned plots. Both average rates and final infiltration rates were higher, although differences were small and not statistically significant. The slightly greater initial intake rates and flatter infiltration/time curve (fig. 3) are probably due to the loose porous nature of the soil surface and ash layers in the burn area. No evidence of nonwettability, as reported by Krammes and DeBano⁵ and others, was observed anywhere in the burn area.

Organic matter content was lower on the burned plot as would be expected following a severe fire. Bulk densities were also somewhat lower on the burned plot, again due to the presence of ash layers on the surface.

Calcium, phosphorous, and potassium all showed a significant decrease on the burned area, but nitrogen showed a slight increase. However, nitrogen levels were very low on both the unburned and burned areas and the difference is probably not significant. It was assumed that the soluble nutrients

⁵J. S. Krammes and L. F. DeBano. *Soil wettability: a neglected factor in watershed management. Water Resour. Res.* 1: 283-286, 1965.

had been released by the fire and leached into the coarse-textured soil by snowmelt drainage.

WATER QUALITY

Two surface streams cross the burn area. The largest, Brown's Creek, drains a small alpine lake above the burn area. Brown's Creek has a deeply incised channel, rocky banks, and a steep rocky bed. In some sections, streamside vegetation was untouched by the fire. In other sections, the fire burned close to the banks. The other stream, a small unnamed tributary flowing directly into the reservoir, and subsequently called Charcoal Creek, flows for about one-fourth mile through the burned lodgepole pine forest.

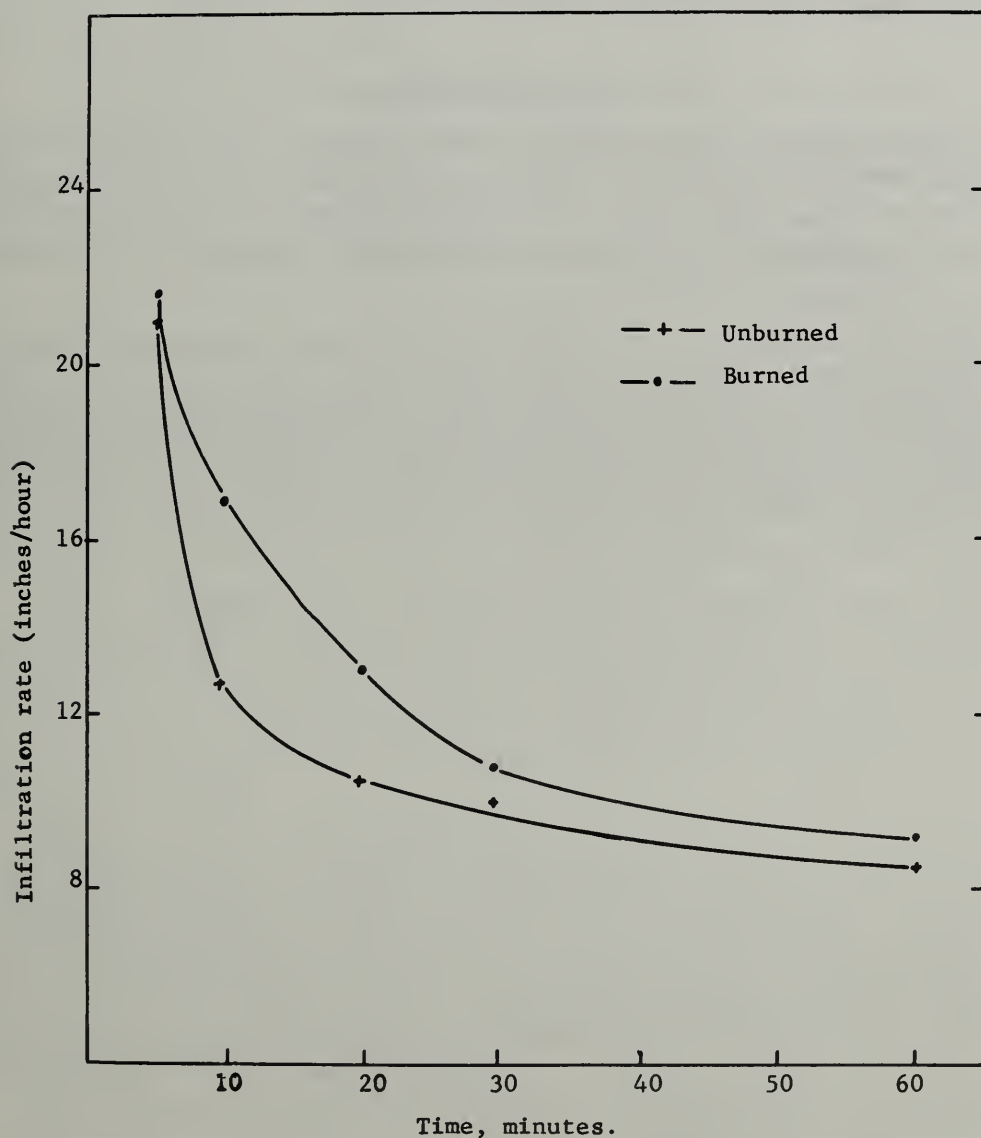


Figure 3.—Infiltration/time curves for the burned and unburned plots.

Stream discharge varied from 7.5 to 0.1 cubic feet per second during the year. Although only a small proportion of the Charcoal Creek basin was burned, it seemed likely that storm runoff and erosion from the burn could influence the quality of water in the stream. Therefore, a small Parshall flume was set in the stream to measure discharge, and periodic samples were collected at the flume and at the point upstream where the stream flowed into the burn area. Stream samples were analyzed for bacteria (coliform, fecal coliform, fecal streptococci), dissolved solids, suspended sediment, turbidity, pH, nitrates, sulfate, and calcium hardness. No direct influence of the burn could be detected in any of these tests. This again may be attributed to the lack of intense storms during the sampling period and the small size of the contributing area in the burn. Perhaps the only direct physical effect of the fire was to expose the stream to sunlight so that, on sunny days, a warming gradient of 2° to 3° F. per 1,000 feet of channel was established.

REVEGETATION

At the beginning of the growing season, the burn area appeared completely devoid of vegetation. However, as the season progressed, vegetation of various types began to appear. A study was begun to evaluate both the initial revegetation and the factors influencing revegetation over the first three growing seasons after the fire.

With the aid of aerial photographs and a map of the burned area, a coordinate grid was designed and 50 random cluster points on the burn were established (fig. 4). At each cluster point, five plots were located randomly. These 250 plots were then located on the ground within the burned area and permanently marked with steel stakes. Around each plot center, three con-



Figure 4.—Distribution of vegetation sampling plots, Comanche Burn.

centric plots were established: a 1-milacre plot on which tree reproduction under 3 feet tall, forbs, and grasses were measured; a 5-milacre plot for shrubs; and a 20-milacre plot for trees over 3 feet in height. Densities were determined by using a modification of the Braun-Blanquet density categories. Each species of shrub, forb, and grass was assigned one of four categories: abundant, common, occasional, or rare. Density of tree reproduction was determined quantitatively by counting the number of individual stems for each species on each plot.

At each cluster point, site and prefire stand conditions were measured. Aspect, slope percent, position on slope, and presence of surface rock were recorded. For the prefire stand, basal area, average tree diameter, and number of stems per acre were determined. Soil samples were taken, and pH and soluble salts were measured. To establish a base for comparison, similar sites adjacent to the burn were established and measured in the same fashion as were the plots on the burn.

The burn was divided into two areas on the basis of the prefire forest types, spruce-fir and lodgepole pine, and data were analyzed separately for the first and third year following the burn. Eighty-five plots were in the spruce area, and the remaining 165 plots were in the lodgepole area. Frequencies of occurrence on the plots are shown in figures 5 and 6.

Tree Reproduction

On the spruce-fir area, tree reproduction occurred on only 4 percent of the plots 1 year after the burn. This had increased to 13 percent at the end of the third year. Lodgepole pine and subalpine fir were the species present and in about equal numbers. Engelmann spruce, the dominant tree in the prefire stand, had not reproduced on the burn at the end of the third year.

On the lodgepole pine area, tree reproduction included two species, lodgepole pine and aspen. One year after the burn, lodgepole pine was found on 39 percent of the plots and aspen on 27 percent, giving tree reproduction on 55 percent of all burned plots. Two years later, lodgepole pine had increased to 46 percent and aspen to 48 percent, giving tree reproduction on 63 percent of all plots.

An analysis using Furnival's binary screen was made to determine which if any of the measured variables were related to the density of lodgepole pine seedlings. Four variables were found to be related significantly to seedling density 1 year after fire: position on slope, density of shrub vegetation, prefire tree basal area, and percent slope. When the data were analyzed 2 years later, only three variables proved significant: aspect, position on slope, and density of herbaceous vegetation.

Aspect, position on slope, and percent slope undoubtedly are related to the tree-water relationship. Because these variables influence available water in a negative fashion, tree density decreased. Tree basal area of prefire stands was related to seed supply. As basal area increased, available seed increased

as did subsequent seedling density. Density of shrubs and density of herbaceous vegetation influenced the occurrence of seedlings through competition. As the density of shrubs and forbs increased, tree seedling density decreased.

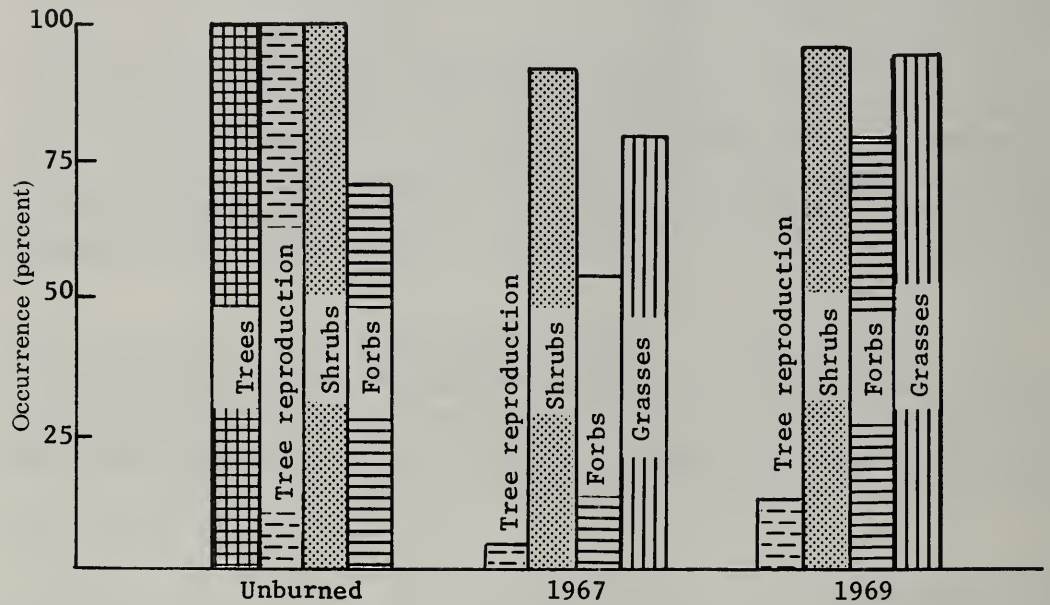


Figure 5.—Frequency of occurrence of vegetation types in the spruce-fir plots, Comanche Burn and adjacent unburned area.

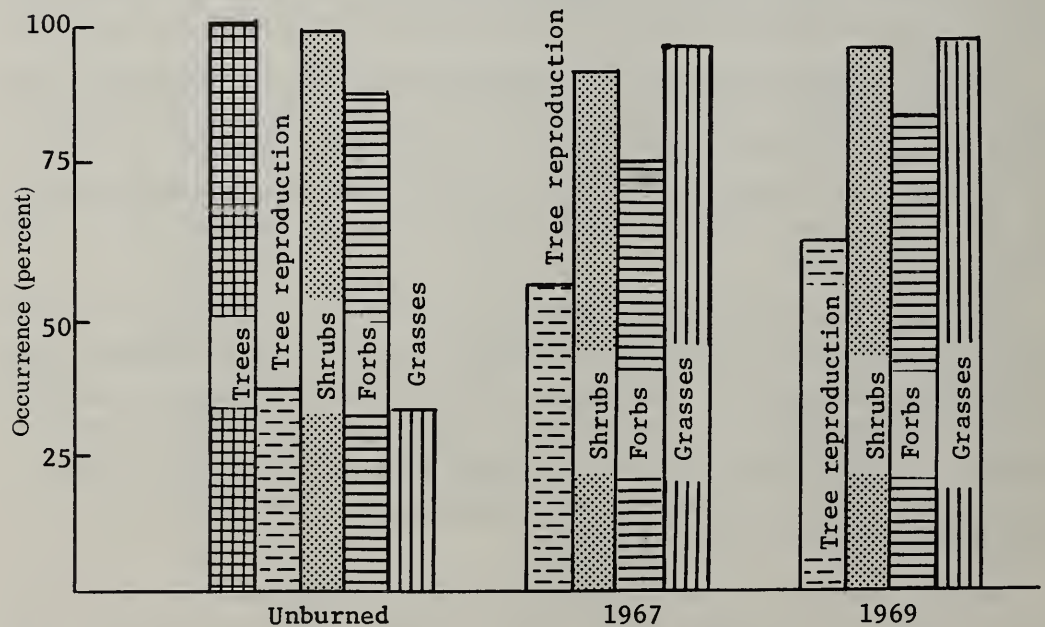


Figure 6.—Frequency of occurrence of vegetation types in the lodgepole pine plots, Comanche Burn and adjacent unburned area.

Subordinate Vegetation

In order to compare the vegetative response following the fire with what was present on the area prior to the burn, a series of similar site plots were established adjacent to the burned area in unburned forest which were considered representative of the prefire conditions on the burn. Comparisons in both areas were made and are shown in figures 5 and 6.

On the lodgepole area, the numbers of species present on the burn in relation to the number found on the similar site were somewhat different. On the similar site plots, 11 species of shrubs were found; whereas on the burn, seven species were present after 1 year and 10 species after 3 years. On the similar site, 11 species of forbs were found; on the burn, 13 species after 1 year and 19 after 3 years. Three species of grasses were present on the similar sites; on the burn, seven species after 1 year and nine after 3 years. The presence of four of the species of grasses on the burn resulted from artificial seeding just after the burn.

Summary

Spruce-Fir Area

Tree reproduction in this area was sparse. Density after 1 year was 3.5 seedlings per acre and increased to only 22.4 seedlings per acre after 3 years. The failure of this area to restock was attributed to lack of adequate seed source.

A total of 20 subordinate species were found 1 year after the burn compared with 29 found 2 years later. Species that sprouted from surviving rootstock were shade tolerant and perennial. Invading species, 87 percent of the species recorded, were generally intolerant of shade, and many were annuals. Density of subordinate vegetation was highest in moist locations. The density index increased during the study period, but at the end of the third year, it was only a fraction of the density index calculated for the unburned stand.

Lodgepole Area

Tree reproduction in the portion of this area that was primarily aspen in the prefire forest consisted of numerous aspen suckers and a few widely scattered lodgepole pine seedlings. Suckers increased from 686 per acre 1 year after fire to 23,909 per acre 2 years later. Occurrence of aspen suckers was due to the abundance of this species in the prefire stand.

In the typically lodgepole pine stands, most pine seedlings were established the first year after the fire. Density was 1,385 seedlings per acre 3 years following the fire which was only a slight increase over the 1,185 per acre noted after 1 year. Seedling density increased as position on slope decreased and as herbaceous and shrub densities decreased. Moisture was considered to be the key factor in reproduction density.

Subordinate vegetation was present on 97 percent of plots 1 year following the fire. Of the 46 different species recorded, 17 were recorded 1 year after fire and 43 were recorded 2 years later. The grass layer had the highest density index and the forb layer the lowest even though 48 percent of the plant species on the burn were forbs. In general terms, the subordinate vegetation was favored by areas with low position on slope, a high prefire tree basal area, and a greater number of prefire tree stems per acre. Such sites had the deeper soils, were shaded by residual snags, and were generally moist. Although fewer species were found on the unburned stands, the density index was about the same as for the burned stands.

Effects of fire and fire control on soil and water relations in northern forests— a preliminary review¹

Abstract

Research data and literature are sparse on fire in the taiga and subarctic zones, especially regarding effects of fire on soil and water relations and on associated resource management considerations. In the scattered existing work, there is disagreement regarding effects of fire on soil temperatures, permafrost degradation, destruction of the organic mat, soil erosion, and other factors; but this is partially expected considering the wide variation in soils, geology, climate, and vegetation of subarctic data sources. Some observers indicate more serious damage from past fire suppression methods than from the fires themselves. A brief, preliminary review of work pertaining to effects of fire in northern forests is presented. Much additional work is needed to delineate the problems and relationships.

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Alaska, one-fifth the size of the contiguous 48 States, has been greatly affected by fires, and over 80 percent of the interior has been burned or reburned in recent history. Alaskan fires burn an average of 1.1 million acres annually; in severe years, they burn several million acres (11). Suppression costs for 1969 were an estimated \$24 million for 512 fires which burned 4,231,711 acres and involved construction of several hundred miles of firelines. Some \$17 million damage resulted even so.²

Recovery in the boreal forest zones is much slower than in other climes and may require 150 years for a spruce stand or a caribou lichen range. Actual erosion and siltation of streams are only suspected. Effects of fire and of control on permafrost areas is a critical but relatively unknown factor. In many situations, a thick vegetative mat exerts principal control on the soil thermal regime. When this mat is modified or removed, the frozen-in-place silt can display marked mobility upon melting. Slippage of soil and siltation of streams can be severe even on seemingly slopeless terrain.

¹This work was supported in part by the Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture (grant FS-PNW-Gr 1-71).

²Preliminary statistics, Alaska Forest Fire Council, 1970.

Hutchison (13), Lutz (28, 30), and Zasada and Gregory (41) provide recent analyses of the present and historical status of forest resources of interior Alaska.

Literature on fire was summarized by Cushwa (8), primarily with reference to the lower 48 States. Korchagin (16) and Beliakov (5) describe work on fire in Russia; Kujala (18), for northern Finland; and Ugglä (40), for northern Sweden, with some reference to effects of fire. A compilation of Canadian fire research literature was prepared by Ramsey (35) and a bibliography on fire in far northern regions was presented by Larson (20). Those works present a compilation of work on fire in the northern climes in general. However, as Hardy and Franks (11) state, "Literature pertinent to fire and control in interior Alaska is scarce." Much of this limited research work in Alaska to date has necessarily been on the more immediate demands of fire prediction, fire danger indices, and fire control, rather than on long-range effects of fire relative to the environment and to resource management objectives. Lutz's work (22, 23, 24, 25, 26, 27, 28, 29, 30, 31) on fire ecology is the primary base of such information in Alaska.

A comprehensive analysis of Alaskan fire activity and statistics to 1958 was prepared by Hardy and Franks (11) and was updated to 1965 by Barney (3). Frail's report³ provides experience from a prescribed burn in southeastern Alaska, though such information probably does not apply to the subarctic interior.

Organic Matter

Work on soil-plant-moisture effects from fire appears to be relatively nonexistent for Alaska and what little information is available is highly contradictory. Organic material is integrally related to soil condition and especially to the water relations. Austin and Baisinger (2), working in the Pacific Northwest, considered the removal of organic matter by fire as having more significance than all other effects combined. They noted the beneficial importance of unincorporated organic matter as an agent in: (1) improving soil aeration, (2) storing plant nutrients, (3) reducing moisture losses through evaporation, (4) improving soil structure, (5) inhibiting compaction and crusting, (6) checking erosion, and (7) increasing water-holding capacities.

Scotter (36) indicates serious destruction of the organic layer by fires in northern Canada resulting in exposure of as much as 35 to 40 percent of the mineral-soil surface area. Similarly, in Alaska, Lutz (25) observed burning to mineral soil involving 30 to 40 percent of the surface area even in fires so severe as to kill all trees. Other observers have indicated lower exposures. Lotspeich et al. (21) in their study of the 1967 Chicken Fire in eastern interior Alaska found that the organic layer was not burned down to mineral soil. Henderson and Muraro (12) discuss effects of moisture content of the organic layer on forest fires. Of course, fuel and burning conditions cause

³Lynn D. Frail. *Report of prescribed burn, Strapass #2, Kosciusko Island. 1962. Unpublished report on file at South Tongass National Forest, Juneau, Alaska.*

variations in response, but there seems to be little quantitative information to indicate relative importance of the various factors or to quantitatively describe which situations are most common throughout the northern vegetation types.

Water Relations

Lutz (25) postulates that the overall moisture relation effects from fire are more pronounced on the southern slopes where the moisture balance is more critical. Quirk and Sykes (34) found soil moisture contents 10-15 percent higher in unburned spruce than on a previously burned south slope, but they implied this factor to be causal in preventing fire rather than an effect from fire. Patric and Black (33) provide evapotranspiration criteria adapted to Alaska, but the sparsity of long-term climatic data made computations difficult and highly variable. They indicate that the University Experiment Station at Fairbanks is the only station in the State with sufficient published data to allow comparison by all of the three most common methods: Penman, Thornthwaite, and evaporation pan.

Hydrology and Erosion

There is little information or agreement on the hydrological effects of fire in Alaskan taiga zones. Shimkin (38) indicates that, due to permanently frozen ground in the Arctic areas, the flooding, eroding, and silt-carrying capacities of Arctic rivers are nearly four times as great as experienced in temperate areas. Many knowledgeable local residents and resource observers indicate serious erosion from burned areas. Ellsworth and Davenport (10) in their 1915 work in the Yukon-Tanana region suggest that the heavy moss layer is the principal regulator in the distribution of the summer runoff, and they cite examples and local opinions wherein burned-over areas yield more rapid "flashy" runoff. Bob Marshall (32) and Auer (1) express similar sentiment. After a recent fire in the Salcha River headwaters, the Big Delta Soil Conservation Sub-District expressed concern over the serious erosion and siltation of the river.

However, Lutz (25) indicates erosion on burned-over areas is surprisingly small in spite of the fact that the soil properties would lead one to conclude that they were easily eroded. Scotter (36) feels erosion following forest fires in northern Saskatchewan is not serious. In fact, several years after a burn, he found increased infiltration rates on the burned-over soils compared with unburned soil and felt this would reduce the threat of erosion. This infiltration data is in contrast to that of other workers in temperate zones where infiltration rates on burned-over areas have been slower than on unburned areas (4, 7, 15), some as much as 40 percent slower (14). In California, uneven penetration of soil moisture after fires has been attributed to a hydrophobic organic coating of soil particles, sometimes even preventing water penetration beyond 1 or 2 inches into dry soil (17).

Fire Control Lines

Many observers indicate more serious damage from present fire suppression methods than from the fire itself. For example, Lotspeich et al. (21) in their study of the 1967 Chicken Fire found negligible indication of erosion in actual burned areas but drastic erosion and degradation along fire control lines and "cat trails." On some permafrost terrain, even in seemingly flat basins of imperceptible slope, the severity of such catline erosion and the soil volume displacement can be astonishing at times. The insulative mat of mosses and lichens is usually 4 to 12 inches thick and, even in late summer, the underlying active (seasonal thaw) layer of soil frequently has a maximum depth of only 5-10 inches. The permanently frozen soil below may range from low to high in ice (water) content. Of course, for an effective fireline, the mat must be completely removed, leaving mineral soil. Open, thus, to long-day radiation without an insulative cover the thermal degradation and erosion can take place readily.

Lachenbruch (19) made theoretical estimates of effects of a heated pipeline in permafrost, causing thermal degradation of high ice-content soil into a slurry condition. Adapting Lachenbruch's figures for laminar flow of viscoplastic fluids to a soil slurry (of 10^3 poise viscosity) 6 inches deep in the trench of an eroding catline, an astonishing flow rate is projected of 0.05 mile per day on a "flat" slope of only 1 foot per mile. Theoretical velocity of flow on only a 25-foot-per-mile slope is 1 mile per day. Increasing the depth of the slurry layer fivefold increases the theoretical velocity by 20 times. Though this comparison is admittedly a tenuous adaptation, it does point out the great potential instability of permafrost soil exposed by fireline construction.

The residual effects from fire control techniques have caused considerable concern among resource managers (9), and various in-service reports and rehabilitation endeavors have been undertaken during recent years. The Bureau of Land Management initiated one such administrative revegetation study in 1969 near the Taylor Highway in eastern Alaska (6).

Soil Temperature

Soil temperature regimes are significantly altered by fire. Most workers in temperate zones, except Shirley (39), have found increased temperatures on burned-over areas as a result of removal of insulative material and greater absorbance of radiant energy by the darker, charred surface. Kittredge (15) found a 20° F. difference at the 1-inch depth. In interior Alaska, Quirk and Sykes (34) observed a 5° F. higher soil temperature at 1 inch in a previously burned 40-year-old birch stand compared with a 200-year-old white spruce stand; such differences penetrated the profile to over 16 inches. Scotter (36) found burned-over areas in northern Saskatchewan to average 10.5° F. higher at the 1-inch depth and 9.7° F. at the 3-inch depth. Such relationships are

confirmed by Lutz (25) and numerous observations have been made on the resulting recession of the permafrost zone after fire. Lotspeich et al. (21), however, found no change in depth of permafrost in their study 1 year after the burn.

Summary

Though many discrepancies are evident in the existing literature, this is to be expected considering the vast, widely separated regions from which the meager data are derived and the differences in soil, geology, climate, vegetation, and fire control activities. Several study projects are underway, however. It is clear that much work is critically needed to delineate the problems and the relationships involved.

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Effects of fire in the taiga on the environment

Abstract

Findings from a study of fire effects on the aquatic environment lead to the conclusion that the fire had fewer deleterious effects than did activities from fighting the fire—improper siting of “cat” lines as an example. These findings were important in decisions by land management agencies to revise recommended firefighting methods.

In Alaska, and in other areas with similar climates, the presence of permafrost is a complicating factor that requires careful consideration when making decisions on where and how to contain a fire. A selected control strategy may result in more damage than letting a given fire spread and burn itself out. Heavy applications of phosphate-base retardants may cause early eutrophication of lakes. A decision must be made on intensive versus nominal efforts to control a given fire; each is unique and the total ecosystem, with variations, must be considered in addition to the economic value of the forest resource—all these lead to the conclusion that decisions on how to fight extensive wildfires in the taiga require knowledge that frequently is not available. Lack of such information may result in some unexpected side effects. All land managers must constantly seek to improve their understanding of the taiga ecosystem to better prepare them to make decisions regarding where the effects of a chosen plan of action will lead.

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Introduction

A study investigating the effects of forest fires on water quality was reported by the Alaska Water Laboratory, Federal Water Quality Administration, in February 1970. The fire area studied is located east of the Taylor Highway near Chicken, Alaska. The fire was started by lightning on July 23, 1966; and by September 13, when it was brought under control, more than 250,000 acres had burned.

The watersheds of a number of small streams were completely burned. In addition, large areas of the drainage basin of larger streams such as the West Fork, Dennison River, and Big Timber Creek were also burned. Sampling stations were established above, within, and below the burned areas. Sites were sampled for soil and water chemistry and aquatic bottom fauna for 2 years following the fire.

This study concluded that fire fighting activities may contribute as much to water pollution as do the residual effects of the fire. Specifically, pollution of water, as defined in this study, was caused by three constituents—silt, organic material, and soluble salts. Stream turbidity, originating from silt released by erosion from bulldozed fireline construction, was significant for several summer seasons following the fire. This persistent source of pollutant arose because fireline planning did not consider the long-term effects of erosion as influenced by permafrost that continued melting after the fire was out. Organics released by the burning and washed into the streams were considered as less significant pollutants, although they did contribute to additional turbidity for from 1 to 2 years after burning. These effects gradually decreased as vegetation became established, and permafrost had less influence on organic material than on erosion. The third pollutant, soluble salts, was added in small quantity and is not believed to be significant although increases of greater magnitude may be significant immediately after a fire.

As a direct result of these conclusions, Bureau of Land Management revised their firefighting procedures to avoid extensive erosion of fire trails and the resulting sedimentation. Fire suppression supervisors have been issued revised instructions to carefully consider potential erosion problems when establishing fire trails. Let us now turn to other aspects of fire—both wild and controlled.

Effects of Fire Other than Those Resulting from Suppression

When deciding whether to attempt fire control in wild lands, several factors must be considered. Not only the economic value of the resource comes under scrutiny but also the probable effects and costs of suppression. It must be recognized that the Alaska vegetational mosaic resulted from fire and that wildlife migrations evolved under these shifting fire patterns. Only periodic burning can preserve a vegetational complex that constitutes range for much wildlife. Normal plant succession after severe burning results in slowly changing habitats that certain native game species require. The decision to alter this pattern by controlling fire or permitting burning should result from a consideration of factors in addition to the threat to human habitation and economic values.

If burning is not severe enough to destroy the usual deep moss cover of most of the taiga, erosion does not present a problem. Permafrost may melt to greater depths for a few years after a fire, but this seldom introduces a problem of erosion unless the overlying vegetation mat is removed, either by severe burning or heavy equipment. Once melting starts on exposed soil, it releases silt that may cause sedimentation of stream waters—even where gradients are so gentle they would not erode normally. The release of silt through melting, rather than true erosion, is the factor that may cause sedimentation of streams draining a burned area.

Soluble organics may be released by the burning process and give brown colors to streams. However, many streams of the taiga are naturally brown from organics leached from muskeg areas within the drainage basin. Whether an increase in color as a result of fire interferes with the normal functioning of the aquatic ecosystem is a matter of conjecture at this time. These aquatic communities evolved and are living in highly colored waters; however, their tolerance of higher concentrations of these colored organic substances is unknown.

Soluble salts released by burning may be lost to the soil and enter the surface waters under certain runoff conditions. However, resultant concentrations are relatively low and may never reach levels that could be termed serious pollution problems.

Introduction of Chemicals from Retardants Used in Fire Control

Since many fires occur in areas inaccessible to ground crews, heavy use is made of chemical retardants dropped from planes. One of the main materials now being used is a compound containing ammonium phosphate with trace quantities of ferric oxide and an organic binder. When used in heavy concentrations, it can cause an unacceptably high concentration of nitrogen and phosphorous nutrients in streams and lakes. Eutrophication is a much more serious phenomenon in lakes than in streams, because lakes act as a sink collecting phosphates and high levels of this nutrient might seriously change the lake ecosystem.

Sometimes the decisionmaker must use retardants intensively regardless of effects on other resources—an example might be when a community or village is threatened by fire and intensive use of retardant may prevent heavy damage. At any rate, the decision on whether, where, when, and how to use chemical retardants depends on factors that must be known in advance of an action; therefore, some estimate of results must be predicted. Knowledge of ecosystem dynamics and how they react to fire and efforts to control it, is a worthy requirement of fire control supervisors. With such information, fire control supervisors can make rational decisions on whether an intense or minimal effort with chemicals can be made with minimum damage to other affected resources.

Economics and Ecology

Before an intense fire-fighting effort is mobilized, the economic worth of the total burned area must be considered. Control efforts might cost more than the economic value of the resource that is presumed to be destroyed by fire. This is especially relevant when burning might even enhance the value of wildlife range and no other more valuable resource is threatened. Recent studies in Minnesota and Georgia indicate that fire may be used as an ecological tool to increase the value of given areas. Scenic values may far outweigh any economic consideration and require an intense effort of control even though the area has a low overall value as timber or wildlife range. However, before a decision is made to control or not control a fire, fire control supervisors must be in a position of strength, through ecological knowledge, and be able to predict what will be the result of a given course of action.

Smoke from extensive fires is certainly an economic factor through its effect on visibility and as an irritant. Aircraft may be unable to make scheduled landings when smoke is thick. As an irritant to all life, smoke has received little attention but probably has some disagreeable effects even if only temporary. The effects of many days of thick smoke on the taiga forest is unknown, but intuitively we can reason that restriction of light and irritation have deleterious effects. Thus, the effects of smoke must be considered as a factor when deciding on the course of action to be taken to control wildfire.

Physical Factors to Consider

Several physical factors of the taiga ecosystem influence the ultimate outcome of a previously planned system of fire control and the resultant effect on the aquatic environment. One such factor, permafrost, was discussed earlier and can be suspected to be discontinuous throughout interior Alaska. The planning of firelines and clearing operations must always consider effects from permafrost disturbance. Failure to adequately appraise permafrost can result in long-lasting erosion that may be more serious than the total effect of burning. Through proper site planning for equipment-constructed fire trails, obvious areas of ice can be avoided and trails restricted to well-drained rocky areas as much as possible.

Geomorphology influences the course of a fire—shape and slope of hills help determine rate and extent of burning; aspect or direction of exposure may limit one slope to a particular environmental climax community in contrast to one entirely different on the opposite slope. These contrasting climaxes (or successional units) may have different rates of burning: the climax forest may be stunted black spruce on northern slopes and birch and white spruce on the south slope. Valley-ridge systems and prevailing winds also influence fire planning. Contrasting slope directions may also have dif-

fering depths of moss cover. If a fire is not severe enough to destroy this protective cover, erosion may not be serious unless fire trails have removed this cover.

Precipitation and relative humidity are important factors governing the planned suppression of fires. If heavier than usual rainfall precedes a fire, the moss layer will contain more moisture and resist burning, whereas drier than usual conditions may result in complete destruction of the protective moss layer. Under these latter conditions, erosion may become serious with resultant extensive stream sedimentation. The quantity of fuel available also strongly influences the severity of burning. If a burn passes through a healthy forest, less flammable fuel is available than on an area burned a few years before where the trees have been killed and allowed to dry while standing.

Need for More Ecological Knowledge

Throughout this discussion, we have stressed that decisions being made on how to control wildfires in the taiga should and must depend on environmental knowledge. A wrong decision may have unexpected results, usually to the environment's detriment. The work referred to earlier is an example of an area where fire fighting methods may have resulted in more damage to water quality than did the fire itself. Persons responsible for making these far-reaching judgments need information that many times is not available, and they reach a decision based on experience or conjecture. Badly needed is a research program to study the ecological, social, and economic effects of fires in the taiga.

Only by having information derived from previous research can evaluations be made of the consequences of a decided course of action. The research referred to in the introduction was a small step toward understanding how wildfire affects our aquatic environment. A long-range program of field investigation to study all aspects of fire ecology in the taiga is needed. Such research should include the study of direct, immediate effects of fire on soils, vegetation, and wildlife and how these in turn affect the aquatic ecosystems. Long-range objectives should be the study of plant and animal succession to establish criteria for predicting results of a given fire under controlled and uncontrolled circumstances.

Even with present incomplete information, much can be accomplished in predicting the results of a particular course of action if all persons making such decisions are aware of environmental factors and how they may be used. Supervisors at all levels and other professional persons likely to become involved in fire control should constantly strive to improve their knowledge of ecology and environmental requirements of the taiga. By applying management practices that have a predictable effect, we can avoid some consequences of poor judgments based on "hunches" or otherwise questionable reasons for decisionmaking.

All managers of renewable resources should be thoroughly trained in the theory and practice of ecological management of natural resources. Emphasis in the past has been on the economic aspect of management; hence, the ecosystems have not received the attention they deserve. As we gain more and more understanding of ecosystem dynamics, ecomanagers can apply their knowledge to the management of a given natural unit and gain the optimum benefit from it without damaging other associated resources. Most laws and regulations have been written for the benefit of man and seldom do managers consider the requirements of the ecosystems involved. Ultimately all of man's existence depends on maintaining an environment suitable to sustain all life, however fragile, not man's exclusively. Unless we take immediate action to gain and apply ecological knowledge to forestall predictable deleterious consequences of our activities, we will be faced with the alternative of a deteriorating worldwide environment.

In the taiga, fire is only one of these environmental factors; but because of its overriding control over the life pattern in this area, we must learn to use it to gain the optimum benefits for this biome. When this management concept is attained, man will also benefit, because as we learn to live ecologically as part of any biome, we stand to gain in the long run by less destruction of the base upon which we depend for survival.

Wildfires in Alaska— some historical and projected effects and aspects

Abstract

This paper discusses some of the historical aspects of wildfires in interior Alaska with particular reference to the period from 1940 to the present. Several speculations are made on the basis of recent records relative to fire impact or effects. The need to obtain quantitative impact information is also discussed.

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Introduction

Wildfires in Alaska are often a topic for discussion. This is true not only among fire control personnel but also resource managers, scientists, and laymen. It is a subject that everyone talks about with authority whether or not they have participated actively in fire control.

There appears to be an ever increasing controversy on whether to control or not to control wildfire in Alaska with an array of positions between. A recent article in *Science* by Mark Oberle (15) is a good example of growing dissent relative to possible ecological drawbacks of Alaskan fire suppression policies. Wildfire is becoming increasingly important from both an ecological and economical point of view. Environmental groups and the general public are showing increasing interest and concern centered around the role of wildfire in perpetuating the type of environment desired on one hand and in the destruction and waste on the other.

The intent of this paper is to develop a perspective into some of the quantitative aspects of Alaskan wildfires. The discussion will provide a more or less common basis on which to view the role of wildfire in the northern environment. Information is presented on both statistical-fact and statistical-projection bases. The latter has been developed with data, comments, concepts and ideas, both my own and those of others interjected throughout. Perhaps this paper will stimulate thoughts toward a new outlook by which to view the entire subject of wildfire and its place and problems in the northern environment.

Historical Information

It is conceivable that lightning as an ignition source and fuels to produce fires have been present in the taiga since the glacial epoch. The problem is in determining how long and how much wildfire has been present in this region and if it was present in any abundance before man arrived upon the scene.

Although evidence is relatively sparse, it would appear that aboriginal man played an important part in the cause of historical fire in the northern regions (12). This early use, in conjunction with camping, signaling, hunting, combating insect pests, and other applications, led to numerous wildfires. In general, aboriginal man was quite careless with fire. Apparently, whenever the weather was warm and dry, either man or lightning could start fires in the taiga.

The problem increased with the coming of civilized man. This "newcomer" to the northern country was perhaps more careless with fire than was the native. The modern man's reasons for fire use were much the same as the aborigines. However, several new reasons for fire use were added to the list such as land clearing, forage production for livestock, and mineral exploration activities. The addition to the native population already in the country increased total number of ignition sources and fire starts. With no organized fire control in this period of settlement, more and more country was being burned at a faster rate than before. Much land was being reburned. This changing pattern of fire occurrence resulted in a changing pattern throughout the landscape. At the turn of the century or slightly earlier, 1890-98, the period in which gold was discovered, fire activity increased as thousands of men and women came north to seek their fortunes.

Although formal fire records as we know them today were not kept before the 1940's, it has been reported that several thousand acres of forest land were burned as a result of mining and exploration activities. During the period, 1893-1937, in excess of 6,100,000 acres were reported blackened by just 19 individual fires (11). It has been stated that an average of at least 1 million acres was burned each year from 1898-1940. In 1940, the Alaska fire control service was organized (10). In light of subsequent statistical information, the preceding acreage burned figure appears to be conservative. During the first decade of organized fire control action, more than 1.2 million acres were burned per year on the average. Because detection was basically limited to accessible roads, this figure could be conservative too. In any case, an average annual burn for the 1900-40 period of 1.5 to 2.5 million acres seems more reasonable than the previously accepted 1-million-acre figure.

Wildfire statistics are available and have been compiled for the period of 1940-69 (2, 3, 6). The average annual burn for this period is approximately 1 million acres. Man still plays an important part in the fire history of this country. On a 30-year basis, slightly over 70 percent of the fires have been man-caused, and these same fires have burned 22 percent of the acreage. Figure 1 shows these data graphically. The annual number of fires seems to show a generally climbing trend, but annual burned acreage appears to be decreasing.

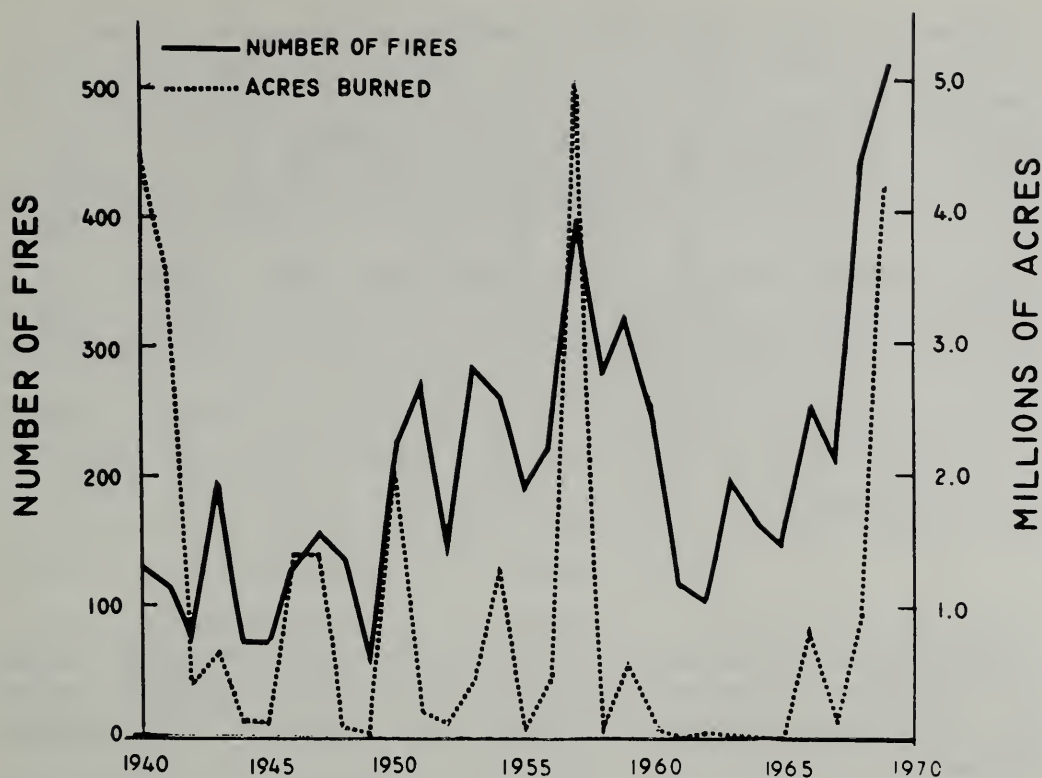


Figure 1.—Number of fires and acres burned by year, interior Alaska, 1940-69.

The increase in number of fires over the past 30 years is in part due to the increased activities of man in this country as well as improvements in detection and reporting of fires. In the early days of organized fire control, suppression activities were generally limited to access via railroads, highways, and waterways. The apparent trend in reduction of acreage burned is undoubtedly a direct result of improved detection and more aggressive suppression action.

During the decade of the 1940's, 1,138 fires burned 12.4 million acres in the interior of Alaska. The decade of the 1950's saw an increase in the number of fires to 2,583, but burned acreage was reduced to approximately 10.7 million acres. The 10-year fire total for the 1960's was generally similar to the preceding decade with 2,380 fires recorded. Acreage burned during this most recent decade, however, took a significant drop to about 6.4 million acres. This acreage-burned figure was about half of the reported burn of the 1940's. There has also been a decrease in the average size per fire by decade with the 1940's recording 10,906 acres per fire; 1950's, 4,137; and the 1960's, 2,674 (table 1).

Southeastern Alaska is not in the northern environment; however, a brief mention of fire in this portion of the State should help to establish the role of fire in Alaska overall. Although the records are not as impressive, coastal Alaska also has a fire history. For the 12-year period, 1956-67, 243 fires burned 5,403 acres.

TABLE 1.—Number of fires and acres burned by cause and decade, interior Alaska, 1940-69

Decade	Lightning-caused fires				Man-caused fires				Total fires		
	Num- ber	Per- cent	Acres	Per- cent	Num- ber	Per- cent	Acres	Per- cent	Num- ber	Acres	Acres per fire
1940-49	200	17.6	Not available		938	82.4	Not available		1,138	12,411,076	10,906
1950-59	745	25.8	8,502,540	61.8	1,838	74.2	2,183,050	38.2	2,583	10,685,590	4,137
1960-69	853	35.1	4,801,563	71.7	1,527	64.9	1,563,482	28.3	2,380	6,365,045	2,674
1940-69	1,798	29.5	13,304,103 ¹	78.0	4,303	70.5	3,746,532 ¹	22.0	6,101	29,461,711	4,829

¹ 1950-69 only; data for 1940-49 missing.

Man is the primary cause of fire in the coastal Alaska area. Only four of the total fires reported were lightning-caused, and these combined burned only 1 acre. The man-caused fires were, for the most part, caused by local residents (14).

Even though recent records indicate relatively limited fire activity in coastal Alaska, especially from Cordova south or southeastern Alaska, fire has been present in the past. Several old fire scars are evident on the landscape indicating that fires in excess of several thousand acres have burned in the past. Charcoal deposits have been found throughout the area substantiating large fires in years gone by. Although fire is not presently a concern in the area, current and projected harvesting activities may influence conditions to such a point that fire will again play a more active and important role in south coastal Alaska.

IMPACTS OF FIRE — KNOWN

Aside from numbers and acres, fires have had impacts on Alaska which can be translated into some type of quantitative terms. Wildfire-related costs and values in Alaska are high. Total suppression and suppression costs for the 1960's were about \$40 to \$45 million. The current-day market value and replacement costs for fire control improvements, supplies, and equipment in Alaska are estimated at \$15 to \$20 million. As the fire control organization grows and becomes more sophisticated, using today's technology, the costs also grow.

During the 1970 fire season, wages in excess of \$3.6 million were paid to emergency firefighters in Alaska. In addition, 17 aircraft were under contract, nine for detecting fires and eight for spraying retardants. Initial attack crews were supported with 17 helicopters. Twenty-five native villages supplied thirty-six 25-man trained crews. This new and improved initial attack and detection method resulted in a relatively small seasonal loss (4).

Losses in the interior have been calculated, using a figure of from \$1 to \$16 per acre burned. These figures were for timber, seedlings and saplings, watershed, recreation, range, wildlife, and other values. Improvements lost as a result of wildfires are generally considered at their current appraised market value. On this basis, the 1969 fire season has been estimated to be responsible for losses in excess of \$16 million.

Some of the indirect impacts of wildfire can also be important. The interior depends very heavily upon air transportation, and smoke conditions are quite important. For example, during the 1969 season, one Fairbanks air taxi operator reported that severe smoke conditions, a result of numerous fires in the State, caused him to lose flying business worth \$30,000—\$50,000. During that same season, several of the “bush” airfields were officially closed because of the smoke conditions. The tourist business also was affected by the poor visibility conditions. An actual measure of the impact on tourism is impossible to obtain at this time.

Fire suppression efforts were responsible for saving considerable amounts of real property in 1969. Had no control action been taken on the Kenai Moose Range fire, known as the “Swanson River Fire,” it is generally conceded that hundreds of homes and other installations would have been destroyed in the Kenai-Soldotna area. The exact number and value saved can only be speculated.

Fire control operations in the State have essentially excluded wildfire from urban and other areas within easy reach of fire control centers. Although a few exceptions exist, wildfire of any magnitude is seldom seen by the general public in urban areas of Alaska today. This general exclusion of fire in urban and rural areas could well be causing more problems than it is solving. Fuel complexes without fire may build to such a point as to make an extremely dangerous condition. Time will tell.

IMPACTS OF WILDFIRE — SPECULATED AND PROJECTED

Because there are so many unknown ifs connected with Alaskan wildfires and related areas, it is necessary that much of the impact be speculated at this time. Using what information we now have along with our best judgments considering what has happened elsewhere, as well as adjusting basic relationships, we can make some very reasonable projections and assumptions. Basic physical laws and other established relationships are generally applicable here. Essentially, the problem is to supply the right numbers locally to use in the general formula.

When the previous statistics are considered, it seems quite possible that at least 100 million acres, an area the size of Montana, has been burned during the 70 years since the turn of the century. Let's assume that 25 percent of this acreage constitutes reburning of land since the 1900 date. If this is an acceptable estimate, although probably conservative, then 75 million virgin acres burned in the 70-year period. At this rate, we can speculate that the vast majority of interior Alaska has been burned over within the past 200-250 years.

This time period could possibly be too long when we consider normal species rotation ages, white spruce—100-150 years; birch—80-100 years; aspen—60-80 years; and the reported stand-age compositions in the interior (7). Some areas, of course, would have been untouched by fire for longer periods, in some cases over 325 years (5), but these are a very minor portion of the total land area; however, these areas may represent a major portion of the high production sites, i.e., river bottoms.

The most recent figures on commercial timber volumes in Alaska (7) indicate that 14.8 billion cubic feet are located in the interior. Approximately 22.5 million acres of the interior region are classed as commercial timber acreage, which means they produce a minimum of 20 cubic feet of timber per acre per year. The average volume per acre of commercial timber is about 658 cubic feet. A study of fires during a relatively recent 5-year period indicates that about 5 acres of commercial forest land are destroyed for every thousand acres of forested land reported burned (1). Distribution of fire by cause and cover or vegetation type (2) and statistics for acreage burned (3) indicate that about 52 percent of wildfires burn in forested lands (table 2). Using some quick arithmetic, the 100-million-acres-burned figure projected earlier, and the preceding information, we can calculate and estimate that over 171 million cubic feet of total volume has been destroyed since the turn of the century. It should be kept in mind that this figure does not include other fiber loss which falls outside of total volume and growing stock definitions. These categories essentially consider all sound volume up to a 4-inch top. As can be seen, there will be a considerable fiber volume falling outside the limits of a 4-inch top in Alaska's interior.

TABLE 2.—Projected acreage burned by cause, percent, and cover type for period 1950-69¹

Cover type	Lightning-caused fires		Man-caused fires		All fires	
	Per-cent	Acres	Per-cent	Acres	Per-cent	Acres
Conifer	36	4,789,477	36	1,348,751	36	6,138,228
Conifer-broadleaf	11	1,463,451	27	1,011,564	14	2,475,015
Broadleaf	—	—	8	299,723	2	299,723
Tundra	51	6,785,093	15	561,980	43	7,347,073
Other	2	266,082	14	524,514	5	790,596
Total	100	13,304,103	100	3,746,532	100	17,050,635

¹Percent distribution by cause based on 1961-65 data (2) and applied to 1950-69 total acreage figures by cause (3) to project acreage by cause and weighted total acreage and resultant percents.

Considering the acreage of the entire interior and the acres currently in white spruce production, one might speculate that we would have much more of this type if it were not for fires. Although good upland white spruce sites are available, and some do maintain remnant spruce stands, the majority of spruce is found in river bottoms where burning conditions may be less severe. Repeated fires have converted many of the spruce areas to birch and aspen stands (9, 13). Since white spruce is currently the most desirable species commercially, perhaps wildfire should be excluded from the high production, existing, and potential spruce sites.

Recent work on river-bottom sites in interior Alaska indicates that lack of fire in white spruce stands may well cause site degradation. As the stands grow older, a thick moss insulating mat develops which results in a lowering of the soil temperature regimes. Eventually, a permafrost layer develops making site conditions less favorable for white spruce (17). Therefore, one might speculate that, under some conditions, fires can increase site quality and production by destroying the insulation moss and organic layer.

Wildfires have both beneficial and detrimental effects on wildlife. The exact effect depends on the species and the management objectives which are under consideration. Fires can be beneficial in creating good range for moose under proper burning conditions (16), but they can be detrimental to the lichen winter range of the caribou (8). Determination of fire's position is essentially a problem of individual perspective and overall planning goals.

In my opinion, we now have the technical capability to completely exclude wildfire from the interior of Alaska. If our fire control capabilities were equivalent in numbers, dollars, equipment, etc., on a per-acre basis to the Western States, we could probably do the job now, especially if we were to develop the intensive organization such as can be found in southern California. To take action such as this may not be what we want—we may be creating a worse problem than we are solving. We have to ask ourselves if we want to maintain the landscape as is, allow climax vegetation, or what do we want. When these questions are answered, we can determine the place of fire in the environment of the north.

Summary

There is an urgent need to describe and quantify impact and effects of fire beyond the numbers and acres previously discussed. We must be able to do better than just speculate on what the various ramifications are. The economic values and considerations are also required. Where dollar values are not adequate, indexes must be developed. Fire and its role in the northern ecosystem must be placed in the proper perspective in terms of the economy, the ecosystem, and the management objectives. Perhaps this meeting is a start in the right direction.

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The natural role of fire in northern conifer forests¹

Abstract

The primeval conifer forests of North America, with their associated deciduous components, were largely fire-dependent ecosystems. Fire was a key environmental factor in controlling succession, species composition, and age structure of these forests. An almost universal policy of fire exclusion over the last 50 years is superimposing a vegetation succession which is "unnatural" and is often undesirable in terms of resource management. For most forested areas, a fire policy is advocated which involves selective control of wildfires and managed, prescribed burning to duplicate the natural fire regime.

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Preface

This paper was originally delivered to the Intermountain Fire Research Council at Missoula, Montana. But hopefully its theme is also relevant to Alaska's forested interior, as well as to much of the interior of northern North America. Lightning is now recognized as a major cause of fire in Alaska. In fact, Barney's² statistics show that lightning recently has been responsible for most of the acreage burned. Thus fire must be viewed as a powerful natural environmental factor in your ecosystems—and that is the main thrust of my story.

There are some special circumstances in Alaska and the Canadian north that deserve mention in this preface, however. In the northern environment, organic layers gradually accumulate on soil surfaces on most physiographic sites. This tendency is much greater in the far north than on comparable sites farther south. Permafrost occurs on many sites as well. These facts raise additional questions about the role of fire. For example, what is the relation of fire to peat accumulation and site deterioration? What is the natural role of fire in the nutrient cycle of subarctic forests? Do fires retard peat accumulation and recycle nutrients that might otherwise become permanently locked up in organic layers? What is the relation of fire to permafrost?

¹Except for the preface, this paper is reprinted as originally presented at the Symposium, "The Role of Fire in the Intermountain West," October 27-29, 1970, at Missoula, Montana; proceedings published by the Intermountain Fire Research Council, 2705 Spurgin Rd., Missoula, Montana (illustrations added for current publication).

²Barney, Richard J. *Interior Alaska wildfires 1956-1965*. Portland, Oreg., Inst. N. Forest., USDA Forest Serv. Pac. Northwest Forest & Range Exp. Sta., 47 p., illus., 1969.

Would fire exclusion cause increases in organic blankets and consequent expansion of permafrost? What is the long-range role of fire in maintaining the nutritional status of wildlife browse, lichen stands, berry crops, and other plants upon which the northern fauna depend? You need answers to these questions. I cannot supply many—but the questions are there, and they are important.

I see one other circumstance worth noting. It is that so much of the northern interior forest is not of value for timber. I know you have some fine spruce and birch stands along the river valleys. But much of your forest will probably never be exploited for pulpwood or sawtimber. Its chief value may, therefore, lie in its function as wildlife habitat and as an esthetic component of the northern scene. But if this is so, what about the role of fire? Would fire exclusion alter the natural environment in ways detrimental to these other values? If fire *was* part of these ecosystems for millenia, is it not likely that the entire biota—plants and animals alike—were adapted to some natural fire periodicity? These questions are relevant to noncommercial forests and nature reserves everywhere, but they have special meaning in the far north where such a high percentage of the forest is not exploitable. They make research concerning the ecological effects of both fire and fire exclusion even more important than in regions to the south. The alternatives and the values involved are quite different.

With these qualifications, perhaps the balance of this paper will be in context for my new far-northern audience. At least I offer it to you for what it is worth!

THE NATURAL ROLE OF FIRE IN NORTHERN CONIFER FORESTS by Miron L. Heinselman

The primeval conifer forests of northern North America and their associated broadleaf elements were mostly fire-dependent ecosystems. By this I mean that fire was the key environmental factor that initiated new successions, controlled the species composition and age structure of the forests, and produced the vegetation patterns upon which the animal components of the ecosystem also depended. This was certainly true of the forests of northern Minnesota and adjacent Ontario where my current forest history studies and those of Spurr (5) and Frissell (3) apply. I am convinced it was also true of most forests of the Intermountain West (the concern of this symposium), the Rockies, the Pacific Northwest, the Canadian and Alaskan boreal regions, and the Sierran region of California. I base this conclusion on a large body of forest history and autecological literature, and on personal observations in much of the West and North. It is really only a hypothesis, but its validity can be checked with field studies wherever virgin forests still remain.

Fire was the great reaper that periodically eliminated or opened up old forest stands, making way for new generations of trees. The primeval landscape was a vast mosaic of stands in various age classes and successional

stages following fire, interspersed with recently burned areas. Younger stands often had dense, relatively pure, even-aged overstories of such post-fire pioneers as jack pine, lodgepole pine, black spruce, quaking aspen, western larch, or Douglas-fir. Even the mature forests usually had individual trees in the overstory that dated from the last fire. Succession may have greatly modified the composition and structure of these old stands, but the overstory trees may still have been primarily from the first generation after fire. Indeed, this is still true of the virgin forests today, after 50 years of protection from fire. With the longer-lived post-fire species, such as the red, white, ponderosa, and sugar pines, western larch, Douglas-fir, redwood, and sequoia, this first generation can last many hundreds or even thousands of years.

Other forests probably had a stand structure consisting of distinct groups or groves of trees, with the individuals in each group dating from a particular burn that had opened up the old forest at that time. Red pine, ponderosa pine, giant sequoia, and other forest types often exhibit such a structure.

True climax forests of shade-tolerant trees that perpetuated themselves for several generations in the absence of fire were probably uncommon. Such stands did and still do exist, but in most regions I suspect they occurred only on those unusual physiographic sites where fires are rare.

Fire scars on “veteran” trees in our remaining virgin forests still testify to this long history of fire. Charcoal occurs almost universally in the soil profiles of the virgin conifer forests of many regions. And many stands have ancient, charred snags still standing among the present generation of trees, in silent testimony to the forces that brought about their origin.

We have known many of the facts of fire ecology for a long time. If you doubt this, try reading Frederick E. Clements, “Life History of Lodgepole Burn Forests” (1). (As an aside, I must note that Clements found stands dating from 1864 to be the most abundant in his Colorado study, just as I have for the Canoe Area in Minnesota, 60 years later!) What has been lacking so far is not relevant research, but the simple recognition that *fire is part of the natural environment*—that fire is not an unnatural disturbance, and that whole ecosystems have evolved in response to it. We have focused ecological studies on succession to climax and on the identification of climax communities, and neglected the much more prominent “pioneer” and early “seral” stages. It is a paradox that Clements produced one of the first studies of fire ecology and yet was responsible in large measure for our preoccupation with climaxes.

We have known for many years about the adaptations of certain trees, shrubs, and herbs to fire—for instance, the serotinous cones of jack pine and lodgepole pine, the suckering of aspens, the sprouting of birches, oaks, and redwoods, the light wind-blown seeds of pines, spruces, aspens, willows, birches, and alders, and the thick fire-resistant bark of ponderosa pine, red pine, Douglas-fir, and redwood. Adaptations such as these must have evolved through eons of existence in a fire environment. I will not cite specific

references, but details can be found in the Forest Service's *Silvics Handbook* (2).

There is some direct evidence for the long-term presence of fire and fire-adapted tree species in North America. Charcoal layers are common in peat bogs in the north, and some of these layers in Minnesota have been shown by carbon-14 dating to be 3,000 to 8,000 years old or more. A collection of tree fossils from early glacial drift in Minnesota, carbon dated at more than 38,000 years old, contained cones and wood of jack pine and black spruce—both common post-fire species. Some of the wood was charred (4).

Fire may aid the reproduction of trees in one or more of the following ways:

(1) It may reduce competition for moisture, nutrients, heat, and light by temporarily eliminating the overstory or understory trees, shrubs, herbs, grasses, mosses, and lichens.

(2) It may create suitable seedbeds by exposing mineral soil or dense ashes, where moisture and nutrient conditions are more favorable than in the thick, loose litter and humus layers of old stands.

(3) It may trigger the release of large seed supplies (as in the case of the serotinous-cone pines), or stimulate vegetative reproduction (as in the aspens, birches, oaks, redwood, etc.).

(4) It may release quantities of essential mineral elements needed for plant growth. These elements are present in the ash layer, and represent a recycling of nutrients accumulated in the litter, humus, wood, bark, and foliage of the old forest.

Fire also played another role. As the principal agent that destroyed old forests, it kept a significant proportion of each region in young stands. It is well known that young stands are less susceptible to certain insects and diseases, as well as to windfall. Fire must therefore have had a "sanitizing" effect by eliminating stands before these problems overtook them, by "cleaning up" old blowdowns and insect-killed stands, and by keeping much of the forest too young to support insect or disease outbreaks.

For example, in Minnesota and eastern Canada spruce budworm outbreaks seem to require large concentrations of old fir and spruce. Such outbreaks may have been less prevalent in primeval times than now, because fire would have frequently curtailed the expansion of these shade-tolerant climax species. Similarly, large stands of old lodgepole pine and Engelmann spruce are very susceptible to barkbeetle attack. Again, fire may have prevented such concentrations of old stands in primeval times. The barkbeetle epidemics now rampant in the Rockies and the Intermountain West may be a product of fire exclusion. Dwarf-mistletoe on black spruce, lodgepole pine, and other species is another case in point. This parasite is temporarily eliminated when fires remove its host. The host trees usually reproduce easily after fire, but mistletoe does not. Thus fires can "rejuvenate" an old mistletoe-ridden forest—and this was probably the natural check on this

parasite. With fire exclusion we are seeing a vast expansion of mistletoe.

The animal component of these forest ecosystems was also adapted to a fire ecology. Some of our most abundant forest herbivores—deer, moose, elk, snowshoe hare, and beaver—are best adapted to recent burns and early successional stages of the forest—not to climax forests. When the forest matures the open areas disappear, and the young trees, shrubs, and herbs upon which these animals depend disappear. Predators such as the wolf, cougar, fox, and lynx depend on these herbivores, and thus also on periodic disturbance of the forest by fire. This is also true of the ruffed grouse and many other forest birds. Thus the whole ecosystem—plants and animals alike—was geared to periodic fire.

I do not mean to imply that there were no old forests. We know that mature forests covered vast areas, and some of them were well along the successional route to climax. But if we study the record, we will see that fire seems to have been the principal natural agent that periodically set successions back. A random, but very real fire “rotation” insured that few stands reached climax.

The conclusions just sketched out resulted largely from the forest history studies that we have been conducting in the Boundary Waters Canoe Area in Minnesota since 1966. Let me just outline what we have been doing there, and some of the findings that are emerging. This is not the Intermountain West, but the research methods and some of the ecological principles should apply to your region.

The Canoe Area is a unique 1-million-acre lakeland wilderness—the only large unit of the National Wilderness System east of the Rockies. Its present forests are a complex of virgin pine, aspen, birch, spruce, and fir, covering about 400,000 acres, and second growth on logged-over lands. The logging between 1895 and 1940 removed primarily large pine; since then, logging has been mostly for pulp on national forest and state-owned tracts. The goal of our ecological studies is to provide a scientific base for possible future management programs aimed at maintaining, and where necessary restoring, the natural ecosystem, and to help management evaluate policy alternatives and their consequences.

The impact of western man on the Canoe Country began with the fur trade about 1670, but there were no permanent settlements on the periphery, or lumbering, mining, and so on, until about 1875. The present virgin forests are mostly less than 150 years old, although some stands are up to 370 years old. They escaped the early logging mostly because they were too young. But they are just as pristine ecologically as the forests in our western wilderness areas and parks—more so than some, because they have not been grazed.

The objective of my forest history studies is to determine the origin and ecological history of the virgin forests, and to relate their present status to the primeval situation. We have now deciphered this history for about the past 370 years. This was done by: (1) Checking available historical records,

old maps, old government reports, and the General Land Office Survey notes; (2) obtaining the ages of thousands of overstory trees on some 900 study plots scattered across the entire virgin forest and some recently logged stands where remnants were present; (3) obtaining a fire chronology from old fire-scarred trees by counting annual rings from the cambium to the scars. This was done on wedges cut from the scars of more than 100 strategically located trees; (4) mapping forest age classes and fire boundaries throughout the area from these records with the aid of airphotos, forest type maps, and field checks; and (5) studying the age structure and time of reproduction by species in 30 stands scattered across the area.

The following conclusions seem warranted, although they are tentative until the final analyses and fire maps are completed:

(1) At least 80 to 90 percent of the virgin forests can be traced to a post-fire origin. The oldest known stand dates from about 1595 A.D., and the youngest stands of any size from the fires of 1936. Charcoal is almost universal in soil organic layers.

(2) Major fires recurred at 5- to 50-year intervals from at least 1600 A.D. to 1920. Some areas reburned at intervals as long as 200 to 300 years, others as short as 10. One area may have last burned about 350 to 370 years ago.

(3) There may have been an increase in fire from 1800 to 1910 due to the activities of local people, but this is still uncertain.

(4) Since about 1920, only limited areas of virgin forest have burned, due to effective fire control by the Superior National Forest. Fire is no longer an active ecological factor.

(5) Most stands still have a nearly even-aged overstory dating closely from the last fire. Some stands of red and white pine and other species contain groves or scattered trees of two or more age classes, each dating from separate fires. Some sites regenerated slowly and contain a mixture of tree ages.

(6) The areas burned most frequently or intensely are large uplands more distant from natural firebreaks. Jack pine, black spruce, aspen, birch, sprout hardwoods, and fir dominate such areas.

(7) The areas burned least frequently or intensely are sites naturally less subject to fire, such as swamps, ravines, lakeshores, the lower slopes of high ridges, islands, and the east, north, northeast, and southeast sides of larger lakes or streams. White pine, red pine, white spruce, and northern white-cedar are relatively more abundant on such sites.

(8) It is likely that fire was frequent enough in this ecosystem to prevent succession from proceeding far toward the theoretical spruce-fir-birch climax. Most forests today are only first generation stands following fire, and this may always have been true. Even the oldest stands still do not meet the test of self-reproduction without fire, because the oldest individuals still date from the last fire. The lifespans of red and white pine, the spruces, and cedar (300 to 500 years) seem longer than the probable periodicity of fires on

most sites. Even jack pine and aspen can persist for more than 200 years without fire, and few areas escaped longer than this. Thus, understanding the natural vegetation is more a question of the selective regeneration of species after fire, and of post-fire successions, than of understanding a hypothetical climax that might have developed in the absence of fire.

(9) The vegetation that might develop with fire exclusion (present practice) is in a sense unnatural, *and largely unknown to science*. We do not know whether such circumstances have occurred in post-glacial times, and we have no good examples of climax forest today.

How many of the fires in this 370-year period were caused by white men or Indians, and how many were caused by lightning? Lightning was and still is a major cause of fire, but we can be sure that many fires were man-caused. The real question, however, is not the specific cause of ignition for each fire (which can never be determined anyway), but whether the pre-white man, or possibly even pre-Indian, fire regime differed in a major way from that I have described. What we really want to understand is the natural fire regime under which the biota developed.

Fortunately the means may be at hand to do just that! A cooperative study is underway with the University of Minnesota Department of Botany and the University Limnological Research Center to determine the sequence of vegetation changes and the associated fire history for nearly the full post-glacial time period.¹ This is possible because annually laminated organic lake sediments have been discovered in the Lake of the Clouds—a small, deep lake far within the virgin area. Sediment cores have been collected, and the full post-glacial record is present. There are some 9,500 annual layers of sediment (lake mud)—checked by carbon-14 dating. The sediment contains tiny bits of charred wood and plant fragments, as well as the usual plant pollens and other fossils.

By studying the fluctuations in abundance of charcoal and of various plant pollens, the University research team hopes to eventually document the vegetation and fire history of the locale for 9,500 years. By relating fluctuations in charcoal in the upper sediments to our tree ring records of fires near the Lake of the Clouds, it is expected that major fire years can be identified. The work is tedious, and it will take time and more research support to complete this project. Eventually other lakes will also be studied.

But already the project has changed the questions we are asking. The question is no longer, “Was fire a natural factor before the white man came?” It is now, “*How much fire was natural*, and were there changes associated with the buildup of human populations, with the arrival of white men, and with post-glacial climatic fluctuations?”

If you accept in broad outline the picture of the natural role of fire I have just drawn, then what are its implications for wildland management? For silvicultural purposes we had at least better take another hard look at pre-

¹Drs. H. E. Wright, Limnol. Res. Center, and E. J. Cushing, Dep. Botany, Univ. Minn., direct this research with the aid of Albert Swain, Alan Craig, and Steven Anthony.



scribed fire as a tool in obtaining regeneration. It *is* nature's way.

But for Wilderness Areas, National Parks, Research Natural Areas, Wildlife Management Areas, and a variety of other non-commercial forest lands, the implications are far-reaching. First, for all areas where preservation of natural ecosystems is an important public goal we must learn to understand the role of fire, and then provide for that role as expeditiously as possible. The present nearly universal practice of fire exclusion is a very powerful form of vegetation manipulation. And it certainly is not likely to result in ecosystem preservation where the original natural plant and animal communities were fire-dependent. In fact, at present we are inadvertently committing such areas to a grand ecological experiment. We are trying to produce climax communities over an entire landscape, in areas where such a situation probably never existed in nature. Even ecologists cannot foresee the consequences.

One possible consequence is a gradual accumulation of fuels—leading to

the potential for a conflagration if a wildfire finally does escape during extremely dry conditions. The extent to which fire exclusion will influence fuels through the changing forest age classes, vegetation types, and stand conditions is a serious matter that deserves study. Both standing fuels and accumulations of down timber, litter, duff, and humus should be considered. Collaboration of fire scientists, ecologists, entomologists, pathologists, and other specialists will be helpful if projections of fuel conditions into the future are attempted.

Only six fire policy alternatives seem available to managers of wilderness areas, parks, and related nature reserves. Failure to consciously pursue a policy will still result in some combination of these options. The options I now see are:

(1) Attempt fire exclusion and accept the slow but pervasive changes in plant and animal communities that inevitably follow.

(2) Allow "safe" lightning-caused fires to burn; allow also for some other wildfires that cannot be controlled, but extinguish the rest. If this option results in less than the natural fire frequency and burned area, so be it.

(3) Allow "safe" lightning fires to burn, allow for some other wildfires that cannot be controlled, but prescribe enough additional controlled fires to assure the natural fire regime.

(4) Suppress all wildfires to the extent feasible, and duplicate the natural fire regime with prescribed-controlled fires.

(5) Allow all wildfires to burn unchecked unless life or property are directly threatened, and hope that a natural fire regime will result.

(6) Abandon the ideal of natural ecosystems and turn to full-scale vegetation and environmental manipulation by mechanical and chemical means, seeding, planting, and so on. Attempt to produce desired vegetation with the tools of applied forestry.

For most areas I favor either option (3) or (4), depending on the particular fire control, human safety, and property safety considerations of the area. Either would provide approximately the natural fire regime and avoid the risk of letting wildfires get out of hand before control is attempted.

The second option, allowing for "safe" lightning fires and some escapes, but not using prescribed fires, may be acceptable where it would yield close to the natural fire regime. In isolated mountain areas this policy may be valid if there is little possibility of fires escaping to lands outside the wilderness or park.

The last option, mechanized forestry, seems inconsistent with the basic philosophy and objectives of our national parks and wilderness areas. However, it is urged as the only realistic and practical choice by some foresters and by many of the forest industry spokesmen, who point out that a commercial harvest of timber could be obtained as a byproduct. Timber cutting is now practiced in parts of the Boundary Waters Canoe Area, in



Algonquin and Quetico Provincial Parks in Ontario, and in several other large “parks” in Canada and other countries. But in none of the cases with which I am familiar is there a serious attempt to duplicate primeval vegetation conditions following cutting. Unfortunately, this option, without commercial incentives, will have to be resorted to in some auto campgrounds and other high-use sites.

I reject the fifth option, allowing all wildfires to burn, both because it endangers life and property and because with recreational use the location and frequency of fires would be unnatural. We cannot endanger human lives either inside or outside wilderness areas, and we cannot risk damage to commercial forests or to structures outside.

It is clear also that I do not favor the first option—attempted fire

exclusion—except as an interim measure until the necessary expertise in prescribed fire and wildfire management can be developed.

But I must emphasize that in most areas we are not ready to introduce prescribed fires of the kinds required ecologically, or on the scale needed to duplicate the natural regime. Much experimentation will be needed to achieve technical expertise in firing and control methods, in gauging weather and fuel factors, and in understanding the fire prescriptions necessary to achieve the ecological effects of the natural wildfire regime. The size of areas to be burned, the frequency of burning, and the burning techniques all require research. There is no need—and indeed it may be impossible—to burn every year. One might allow or prescribe major burns only once every 10 to 20 years. This will depend on the natural fire frequency as well as on burning weather.

There has already been much research in prescribed burning, and many applications are being made. But for ecosystem applications in the virgin wilderness, I am talking about the introduction of severe ground fires, or even running crown fires in mature forests. In some cases these fires must be severe enough to kill most or all of the trees within the burn. Of course, only a small percentage of the park or wilderness would be burned at any one time. The aim would be to slowly re-establish the primeval distribution of forest age classes and vegetation stages. We have little relevant experience with prescribed burning to achieve this.

Research to develop the needed expertise in both prescribed burning and fire ecology is now underway adjacent to the Boundary Waters Canoe Area and in Sequoia-Kings Canyon National Parks. These studies are new, and much more work is needed in these and many other areas. The enthusiastic cooperation of resource managers, ecologists, fire behavior and prescribed burning specialists, meteorologists, and equipment development experts will be needed to bring prescribed burning for ecosystem management to the operational stage.

We must expand our knowledge of the ecology of many species of plants and animals in a fire-influenced environment—some of this work can be done effectively in conjunction with prescribed burning research. We also need studies of the history of natural ecosystems in many more areas if we are to evaluate present conditions and determine appropriate goals for preservation programs. And baseline inventories of plant and animal communities will be needed in each area if we are to understand and document the effects of future programs.

I would be remiss if I failed to mention one more need—the need to develop public understanding and support for ecologically sound resource programs in wilderness areas and national parks. There is plenty of support for *preservation* in the abstract. But the public needs the unvarnished facts about natural ecosystems, and about the measures that will be needed to restore and maintain these systems. At present there may be a problem with understanding the need for reintroducing fire—a legacy from 40 years of

intensive fire prevention campaigns. This problem prevented our carrying out an otherwise feasible experimental burn just this past August.

I think the public *will* understand, and will support such research if given the facts. A start has been made—note the several recent articles in *Audubon*, *National Parks Magazine*, *Naturalist*, and even *True* magazine. More will be needed, including radio, TV, and press releases, if we are to offset the misconceptions now in the public mind.

But fire *was* part of the nature for eons; and mankind has lived with fire on the landscape since his earliest days as a primitive hunter. The need to retain some examples of the earth's primeval ecosystems is real and urgent. The educational, scientific, and cultural values of such areas will be immeasurable in the man-dominated world we shall soon find ourselves living in. Those of us pursuing careers in fire management, fire behavior research, fire control research, prescribed burning research, or fire ecology have a special opportunity—and a special obligation.

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Fire in park management

Abstract

Most of the existing Alaskan State and National Parks were established to provide for human enjoyment of the natural features and to preserve the area in its natural condition. The natural condition is identified as that occurring before the effects of white man's influence became noticeable. The natural condition is not a single year but represents changing ecological conditions over a long period of time.

In many Parks, fire was an important ecological factor operating to maintain the area in its natural environment.

After State and National Parks are created, one of the first management goals to be put into practice is the suppression of all wildfires.

This suppression of fire, however, results in the development of an unnatural environment, at least in those areas where fire was a natural factor.

Probably the most efficient, inexpensive, and natural way to reestablish the natural environment is with prescribed burning.

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Purposes of Parks

State and National Parks are established to protect their outstanding features and to provide for human enjoyment of these features in a manner that will not destroy or impair the features and values to be preserved. In some areas, historical remains are the main reason, but in others, including the three State parks, one National Park, and two of the three national monuments in Alaska, the natural features are the reason for establishing the park. This paper is concerned with those natural features, primarily biotic in origin, that are affected by fire.

The natural biotic features are identified as the environmental conditions or state that existed prior to white man's arrival on the scene in sufficient numbers to noticeably affect the natural ecology. For the interior of Alaska, this would be before 1898, although there are probably enclaves where man's influence is just now beginning to be felt.

This natural environment that existed prior to white man's arrival cannot be thought of as a given year, such as 1897, but must be considered as a continuum of a continually changing environment over a long period of time. Many ecological factors operated to change this natural environment; for some areas, a very important one was fire, either started by lightning or set by aboriginal man. Historically then, some park areas have probably never experienced a wildfire in the past 1,000 years. Other areas may have had fires on an average of every 5, 10, 50, or 100 years.

Effects of Fire

Fire can have a very dramatic effect on plants and animals. The effects of fire, however, are as varied as the species it affects and the conditions under which it occurs. Differences in topography and burning conditions can rapidly shift a fire from a creeping fire, barely able to perpetuate itself, to a raging inferno.

The temperatures produced in any given fire along with their duration are probably the most critical characteristics. A hot, slow-moving ground fire may kill all vegetation and burn all the organic matter down to mineral soil. This type of fire is extremely destructive, possibly setting the ecological succession cycle back to one of the first stages and creating conditions for massive soil erosion.

A mild, fast, surface fire, however, may burn the dead fuel but destroy little live vegetation and thus have only limited effect. Only when fires have low to moderate intensity and shorter duration can the ability of different species to withstand fire influence their survival. The giant sequoia trees with their thick bark to act as insulation can survive fires that will kill other tree species. Age also plays a role in the survival of woody species. Young trees and bushes are usually more susceptible to fire damage than older ones.

The different degrees of fire intensity and duration along with the various types of plant species result in different effects as shown by plant regeneration, disease and insect occurrence, watershed changes, and future wildfire damage. It is widely recognized that some species of trees, such as Douglas-fir, various pines, aspen, and birch that today cover vast acreage, owe their origin to old fires' preparing a suitable seedbed. In many grasslands, the gradual colonization by woody species is retarded or reversed by fire since most grasses can regenerate after a fire better than woody species.

Disease and insect buildups may follow damaging fires since the dead and injured plants are suitable hosts. Generally this buildup only lasts a few years, but it may be sufficient to kill plants that survived the fire.

Intense wildfires can result in soil erosion, but mild fires may have very little effect. The amount of duff or humus remaining after a fire is a good indication of the degree of soil damage—the more duff remaining, the less the damage. Fire that favors grasses over brush may actually reduce erosion by providing a better ground cover.

In areas where brush is extremely dense, the material killed by fire, but not consumed, may exceed that removed. This sets up conditions where a subsequent burn may be more destructive than the earlier one.

Past Park Management

The “era of preservation” started with the establishment of Yellowstone National Park in 1872 and reached a peak with the establishment of the U.S. Forest Service and National Park Service shortly after the turn of the century. In part, this was a reaction against the excesses of the “era of exploitation” and a realization that our renewable natural assets are not inexhaustible. The establishment of parks usually brought about an intensification of effort for the control of wildfire. Since then, there have been enough examples of extremely destructive wildfires to provide impetus to increased fire suppression activities.

Increasing technology through mechanization has led to more effective fire control, and the acreage burned by wildfires has been gradually reduced over the years. The development of the Bureau of Land Management’s initial attack crews, often led by smokejumpers, is an example of efforts being made to stop wildfires. Along with increasing technology has come the public relations effort characterized by “Smokey the Bear.” Our society is continually reminded that wildfires are bad and that every citizen has to be careful with fire.

The general success of the wildfire suppression activities has produced subtle changes in the environment. With the exclusion of fire, fuel continued to accumulate, whereas the more frequent wildfires of the past had kept this to a minimum. Now when a wildfire does occur, it may have many times the amount of fuel as in the days before fire control, and the destructive force may be greater.

An example of the potential danger resulting from this subtle change is found in Sequoia National Park. There, frequent wildfires in the past had kept fuel quantities low so the heat generated did not damage the mature giant sequoia trees. Today, the understory of white fir and sugar pine presents a threat to the survival of some of the big trees if wildfire should occur.

The other subtle change in the environment is manifested in changes in the ecological communities found in a park. Many plant communities owe their particular composition by species and age to the effects of previous wildfires. Many parks at the time of establishment were a mosaic of various types of plant communities, each having been influenced in some way by the absence or presence of past wildfires.

Today, with fire suppression, plant communities follow the slow change toward the climax community for that site. Where once fire would have slowed or set back the successional process to a more primitive stage, we now have a trend toward uniformity as represented in the climax stage. Historically, the area never may have reached the climax vegetation stage.

Our objective of keeping the area in its natural condition has not been attained. Instead, we have provided conditions for the development of an environment that never may have existed before in that area. To the average tourist, the area still looks natural, but some of the variety of the original environment has been lost.

Future Park Management

One of the important considerations for future park management is the recognition that fire has been, in many areas, a dominant factor in the ecology of the park. The analysis of the past role of fire will require the careful and objective evaluation of the evidence of fire activity. This analysis should include the effects of man on fire occurrence, primarily his fire suppression activities, and to what extent restoration is feasible.

Answers need to be found for such questions as how often did fires occur, and what were the effects of these fires. The answer to the question of what plant communities or ecosystems existing today owe their origin, at least in part, to fire will also give us clues to the importance of fire as an ecological factor. This will be a difficult task, given the interrelationship of fire in the natural ecology and the void of data on some species not of economic importance. Some answers may never be found. It will require maps showing vegetative types and the locations of old burns and the collection of data on the interrelationship of fire on the ecology of plant communities. If possible, the ecological role of fire should be determined for all major species or at least their major communities.

A second consideration for future park management is the development of a policy recognizing that fire can and should be used as a tool for the management of a park in its natural state since it is probably the most efficient, inexpensive, and natural tool available. This is not to imply that wildfires should be allowed to burn, since these fires usually pose too great a destructive threat. A policy of fire for park management is a realization that at certain times and places the beneficial effects of a fire outweigh the negative effects. This management use of fire is called prescribed burning. It is the skillful application of fire to fuels under conditions of weather, fuel moisture, soil moisture, etc. that will allow confinement of the fire to a predetermined area and at the same time will produce the intensity of heat and rate of spread required to accomplish certain planned benefits. The objective is to employ fire scientifically to realize maximum net benefits at minimum damage and costs.

After a fire management policy is accepted, the next step is the development of an ecologically sound and carefully thought out fire management plan. This plan should be tailored to the ecological needs of the ecosystems within a park. It will focus attention on areas where fire is believed to have played a major role in the development of an ecosystem. A fire management plan is part of a general resource management plan and must reflect interrelationship with other management plans.

The fire management plan should indicate if and for what purpose prescribed burning should be used to restore or maintain natural conditions with a minimum of overt effort by man. This will include the identification of the "natural" state desired and the method to obtain this objective. It is based on the evaluation of effects of past fires. However, in the absence of any indications of past fire effects, prescribed burning should not be used.

Another part of the fire management plan will be park maps zoned by aspect, degree of slope, and vegetative type. A correlative index with the base fire danger station is needed for each zone. Eventually, we need an accurate prediction of fire behavior under different conditions for each zone.

We should recognize that it will be impossible to use prescribed burning under conditions as they existed 100 years ago. Parts of the park with high human values, such as a campground, should not be burned. Nor should the entire park be subject to prescribed burning at one time due to the destruction of esthetic values.

The fire management plan also needs to consider hazard reduction as an objective of park management. This is the reduction of fuel by prescribed burning, and its purpose is to lower the destructive effects of a wildfire should one occur. It can play an important role in creating a buffer zone of lower fire danger around high risk areas such as picnic areas, campgrounds, and other developed areas.

The last step of a fire management plan is implementation. This will require trained specialists, experienced in the skillful application of all the data available to insure a successful burn. Experience in fighting fires is not enough. The men in charge must know with reasonable accuracy the effects of a fire under given situations. The specialist must understand that no one factor by itself is controlling, and he must consider all factors in composite. In some cases, he will need to develop techniques for achieving the desired results. But until such time as the effects of fire can be predetermined, prescribed burning should not be practiced.

Another factor the specialist must consider are the tools available to control the prescribed burn in park areas. Heavy equipment may not be allowed. Possibly only men with shovels will be permitted to guide a prescribed fire. It is entirely possible that the right conditions for a successful burn may occur only during certain seasons of the year and then only for a few days or a week or two.

An important function of future park management will be a public relations effort to explain to the public the reason for and need to use prescribed burning as a tool. The fire suppression programs such as "Smokey the Bear" or "Keep Alaska Green" will need to be modified. The public should understand that some fires, set by and under the control of experts, are good and produce a better, more natural environment. It should be stressed that prescribed burning will *not* destroy all vegetation and will be confined to a predetermined area.

To provide guidelines to the public relations program, we need to know how the general public views a burned area. When an area is blackened by fire and vegetation has not yet returned, the public probably considers the sight a disgraceful waste of natural resources. But once vegetation has returned and the charcoal look has worn off, then what do people think? How many people can identify an area as having been burnt 1, 2, 5, or 10 years later? Possibly land managers are more sensitive to fire scars than the general public.

An important side benefit of prescribed burning will be in the field of outdoor education. The composition of plant communities before prescribed burning and their response to it will be a fertile area of environmental education. Prescribed burned areas may be excellent laboratories to illustrate succession of plant communities and the factors that influence succession.

I am deeply indebted to David B. Butts for the many concepts and ideas presented in his report.¹

¹David B. Butts. Fire for management in national parks. Unpublished Master of Science Professional Paper on file at Colorado State University, Fort Collins, Colo. 134 p., 1967.

National Park Service fire policy in National Parks and Monuments

Abstract

The National Park Service has studied certain areas and intends to continually study other Parks, to determine whether or not natural fires will be allowed to burn. It is understood by this Service where natural fires will cause a threat to other land agencies, State or Federal, every effort will be made to assist in the presuppression and suppression of same. Where human life or high value areas are involved, fire suppression will be of prime importance. Human life and wildlife values will be of prime importance. Areas will be evaluated and decisions made relative thereto.

Intensive studies will be undertaken within the next few years so that demarcation of these areas can be made and management decisions can be established before fire occurs.

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Introduction

What is climax vegetation? It appears that we do not know in all cases what it is.

Perhaps a case in point is the giant Sequoia (*Sequoia gigantea*) in California. For many years Sequoia groves were carefully and stringently protected from fire. This included groves outside the National Park Service areas. As a result, an understory of incense-cedar and white fir thrived and reached such heights that buildup was a threat to the giant Sequoias which were thought to be residual of a climax forest. In effect, the cedar and white fir appear to be climax in this area; and because of their growth beneath the Sequoias, they are definitely protected from fire and are a serious threat to a subclimax species, the big trees, that we wish to perpetuate.

After a number of years of study, it became apparent that the Sequoia was dependent upon fire for its existence. Protection from fire caused such a buildup of the climax species, cedar and fir, that a fire in Sequoia groves could crown in the subclimax species that was to be perpetuated. Without this understory, it would have been permissible to permit light fires to burn through Sequoia stands. As is well known, mature *S. gigantea*, because of bark thickness, can well withstand ground fire.

After many years of study and discussion, we decided to establish four or five burning plots in Sequoia National Park and at least two burning plots in Yosemite National Park. Before these areas could be burned, we had to remove the buildup of fir and cedar at considerable expense. This understory was cut and stacked in various safe locations and, at the proper time of year, burned. Following this, prescribed burnings of the *S. gigantea* areas were initiated. Soon the regeneration of Sequoia occurred.

So, it appears that fire is a necessity in certain areas. Upon occasion, it takes a number of years to learn this and, perhaps, to learn it in the most difficult way. It certainly has taken years to overcome the idea that fire should not be allowed in certain areas.

Perhaps you wonder why, as a representative of the National Park Service, an agency dedicated to the preservation of all natural features, I would speak in favor of natural fire in certain cases. Perhaps it would be well to inform you about the reason for the establishment of National Parks.

The National Park Service was established in 1916. Its purpose is to conserve the scenery of natural and historic objects and wildlife within its jurisdiction and to provide for enjoyment of the same in such manner and by such means as to leave these features unimpaired for the enjoyment of future generations. This mandate places the controlling agency between horns of a dilemma.

Prior to the establishment of the National Park Service, a number of areas were set aside as National Parks, and these were administered by various Federal and, in certain cases, State agencies. In 1916, when the Service was established and made the controlling agency of the 16 existing National Parks, policies were established for the management, protection, development, and use of these areas. Since that time, policies and objectives have evolved to a point where they are in conformance with the concepts of the originating Act of the Service.

Presently under National Park Service jurisdiction are three different categories of areas: recreational, historic, and natural. In these categories, management policies differ. For example, in recreational areas the mission is truly that of recreation. Certainly within a recreational area there are historic and natural features that must be protected, but these are within the concept of recreation. In historic areas, the same situation exists—the prime resources to be protected are its historic features.

In the natural area category, the purpose is preservation of superlative examples of our Nation's scenic beauty, wilderness, native wildlife, indigenous plant life, and other values of scientific significance. In this category, we are dealing with National Parks and National Monuments.

Presidential proclamation is legally sufficient to establish a National Monument, but an Act of Congress is required to authorize a National Park. However, the Congress can also establish National Monuments. These areas differ in several significant respects: National Parks generally possess two or

more unique scenic or scientific values of superlative quality, whereas Monuments need only one attribute of either scientific or prehistoric value. Administrative policies are the same for each.

The burning issue is fire. And National Park Service administrative policy says that natural fire is a phenomenon and should be allowed to run its course. It can be quoted:

Any fire threatening ecological resources or physical facilities of a natural area, or any fire burning within a natural area imposing a threat to any resource or physical facility outside the area, will be controlled and extinguished.

The Service will cooperate in programs to control or extinguish any fire originating on lands adjacent to a natural area possessing a threat to natural or ecological resources or facilities of that area.

Any fire in a natural area other than one employed in the management of vegetation and/or wildlife will be controlled and extinguished.

It is fairly obvious that natural fire is now being recognized as a natural phenomenon and should be allowed to run its course. However, before fire is allowed to run, certain areas must be delineated to ascertain whether or not the heretofore mentioned natural or man-constructed facilities will be endangered. It appears that, in the future, wildfires will be permitted to burn. The allowance of fire will be predicated on ecological studies of the areas involved. This makes necessary the study of old existing patterns of vegetation and new ones that have evolved as a result of fire. And again, if human life, public developments, or other agencies' lands are endangered, the fire will be suppressed.

We are very fortunate that, beginning in late 1971, we will have three additional biologists on the Alaska National Park Service staff. One of these will be a plant ecologist, with a prime duty to make vegetative studies relative to natural fire. Investigation by the others will greatly supplement his work.

Our intent during the coming fiscal year is to equip our newly acquired aircraft to make comprehensive photos of vegetation so the ecologists will be able to evaluate the need for fire or the need for its suppression in certain areas.

Effects of forest fire smoke on tourism in Mount McKinley National Park, Alaska

Abstract

Mount McKinley National Park encompasses 3,030 square miles of Alaska and the highest point in North America—20,320-foot Mount McKinley. Many tourists visiting Alaska plan trips specifically to see the scenery and wildlife of the Park. In summer of 1969, extensive wildfires in interior Alaska created widespread smoke palls and obscured much of the scenic attraction of the area. During this period, visitation at the Park was higher than in previous years, but length of stay per visit was lower. Smoke conditions during this season apparently did not greatly affect tourism in Mount McKinley National Park.

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For my part of the National Park Service presentation today, I will make some observations on the effects of forest fire and smoke on tourism in Mount McKinley National Park. I'll use the term "visitor" in lieu of tourist, however, since the latter has an unpleasant connotation for some people. We also believe "visitor" is a more descriptive term. I'll use the 1969 fire season as a basis, since this was the most recent year of large fires and a time with which we had personal experience. We'll attempt to analyze why people come to the Park, what they do when they're there, what we would expect the effects of smoke to be upon these use patterns, and finally, what actually did occur when we had this smoke and fire problem.

The Park is located less than 90 airline miles south of Fairbanks and is 3,030 square miles of alpine tundra, spruce forest, mountains, and glacial streams. There is a potential for large fires, and because the staff is small, we must rely upon the Bureau of Land Management to handle our major fire control activities. This cooperative agreement has been beneficial for us, and we are pleased with the Bureau's assistance and capabilities.

A look at some of the reasons people visit the Park might give us some insight into what will happen when there is heavy smoke in the area. A recent report by the Federal Field Committee for Development Planning in Alaska, especially the chapter entitled "Alaska Recreation and Tourism Resources," listed what their research had shown to be the primary reasons

visitors come to Alaska.

They found that approximately 80 percent of people came to see the scenery and wildlife, and many of these came specifically to see Mount McKinley. Not all of this latter group visited the Park, since the mountain can be seen from many places within the State, and a special visit to the Park is not necessary to fulfill this objective.

Generally, we could say that about a fourth of Alaska visitors make Mount McKinley National Park a prime goal in their visit to the State. Why do they come to the Park? There are several reasons.

The mountain itself, the highest in North America (20,320 feet), is a major attraction. The unparalleled scenery people expect in Alaska is found, in part, within this National Park. Wildlife is certain to be here too; and since animals are protected, you can almost be assured of sighting some as you travel along the main road in the Park. Finally, since this is a National Park, it has an intrinsic value of its own. People travel from many parts of the world to see another National Park; it has a special undefinable meaning and value for them.

How do people visit the Park? Until now, the majority have come by train from either Anchorage or Fairbanks, stayed at the McKinley Park Hotel, and taken the concessioner's bus tour through the Park. Many arrive by private vehicle over the Denali Highway, and we expect many more vehicles when the new Anchorage-Fairbanks Road is completed. Most of those in their own cars camp within the Park, and we have fairly extensive campgrounds. Some people fly to the Park. Many land, but most are satisfied simply to view the scenery in passing.

What would we expect to happen during a summer season when there is much fire activity? The obvious thing, of course, would be a decrease in total visitation. If heavy smoke lessens visibility, you would expect fewer people to even attempt viewing scenery. You might expect a decrease in the length of stay by those people who did arrive. Similarly, I would predict that individual activities would be restricted mainly because of the smoke irritant factor, wildlife restlessness, poor photographic possibilities, etc. Some have suggested that we could expect more visitor complaints and less camping, both in auto campgrounds and in back-country camping. Quite likely, there would be fewer people participating in the bus tours. We would expect a reduction in mountain climbing. Mount McKinley and nearby peaks have popular routes, and a thick layer of smoke around the mountains would probably decrease this sport.

During the summer of 1969, the Park was affected, as was much of Alaska, by extensive fire activity. The interior was very dry, during June especially, and we prohibited all campfires. The Park had several large fires, and a heavy smoke pall covered the terrain, obscuring even the mountain peaks from on-the-ground viewers. This gave us a chance to check our hypotheses, even if we could not use precise investigative techniques and had

to resort to empirical knowledge and hindsight.

First of all, we checked the visitation records for any changes. We asked for observations from residents that had been in the area for some time to see if their observations were close to ours. We consulted the ranger station logs and checked visitor comments in registration books. And finally we tried to recall personal observations and thoughts from the summer.

What did happen? Much to our surprise, visitation did not decrease but increased considerably. It was up several thousand over previous years and was greater than the following year (I think we can assume that the decrease in 1970 was a result of the economic slowdown experienced throughout the country).

I had made an interesting note in the Wonder Lake Ranger Station journal near the end of June 1969, "Mount McKinley has not been visible for 21 straight days." Apparently the word did not get out; or if it did, no one cared, because people came anyway. As suspected, though, there was a decrease in the length of stay by individual visitors. More people arrived, but they left sooner than they normally would.

Individual activities also increased. Back-country use was up, probably because of lack of rain. Photographers became even more zealous to capture the scenes and wildlife on film.

Instead of visitors' complaining about the smoke and heat (and blaming the Government—an easy target), the majority of people expressed concern for the land and fauna and appreciation of the suppression efforts.

Mountain climbing also increased. A reviewing of the expedition reports at the end of the season showed that although there was much smoke at lower elevations, the weather was better than normal at higher points. Once the climbers got above the smoke, they experienced generally good weather.

These results were very unexpected. Although we are not certain of the reason or combination of reasons, the most acceptable explanation seems related to long-range planning. It costs a great deal to come to Alaska, and visitors from other States especially must plan and commit funds long before their trip. Reservations must be made far in advance for tours, and those driving are usually committed to time and goals. It may also be that with the great distance involved, prospective visitors are not aware of conditions they will encounter in the State.

In summary then, I think we can say that Mount McKinley National Park is a major visitor attraction, and heavy smoke or fire will not affect the amount of Park travel but may decrease visitors' lengths of stay. The quality of the experience of visiting this area may also be lessened. Perhaps someday social scientists will be able to help us measure this loss.

These are personal observations and not principles we should apply to all National Parks. The points may not even be valid for Mount McKinley National Park the next time there is a Statewide fire problem.

Fire effects and rehabilitation methods— Swanson-Russian Rivers fires

Abstract

During summer 1969, fires burned 86,000 acres of the Kenai National Moose Range, south-central Alaska; two fires accounted for 99 percent of the burned area. Suppression efforts involved nearly 5,000 men; 135 miles of catline were constructed, and 822,000 gallons of retardant used. Funds allocated for burn rehabilitation totaled \$900,000 for FY 1970 and 1971.

Effects of the fire on wildlife were apparently light. There were no confirmations of dead or burned bear, moose, or caribou; although small mammals probably suffered, 1 year later voles, shrews, and grouse were reinhabiting the burned area (possibly in reduced numbers). There were indications of heavy salmon mortality immediately after the fires, but actual cause was not determined. No long-term effects on fisheries were noted.

Rehabilitation efforts include seeding and fertilizing over 13,000 acres, and using LeTourneau "tree-crushers" to knock down fire-killed trees on 30,000 acres. These efforts appear to be very successful in reducing fire danger from standing snags, aiding animal access to browse species, and improving the overall appearance of the landscape.

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Introduction

Wildfires burned approximately 86,000 acres of forested land on the Kenai National Moose Range during 1969. Of the total land area affected, 99 percent was burned in two fires, the Russian River and Swanson River fires (fig. 1).

The Russian River fire began June 14 in the Chugach National Forest, was contained by the morning of June 15, and was in the process of being mopped up in the afternoon when rapidly rising east winds (from 10-40 knots) reactivated the fire which jumped across the Russian River ravine (approximately one-eighth of a mile wide) onto Moose Range lands. For 5 days, pushed by high afternoon winds, the fire burned 6 miles westward, jumping the Kenai River and up Shelakh Mountain, where it was controlled June 20 after velocities of wind lessened. It had burned 2,600 acres—2,300

of which occurred on Moose Range lands. Mopup continued until June 25 when infrared scanning aircraft reported the fire out.

The U.S. Forest Service was in charge of the fire. They estimated suppression costs at between \$800,000 and \$1 million.

The suppression involved 918 men, 22 pumpers, 13 dozer tractors, and three air tankers. Twenty miles of "catline" were constructed, and 91,000 gallons of fire retardant were dropped.

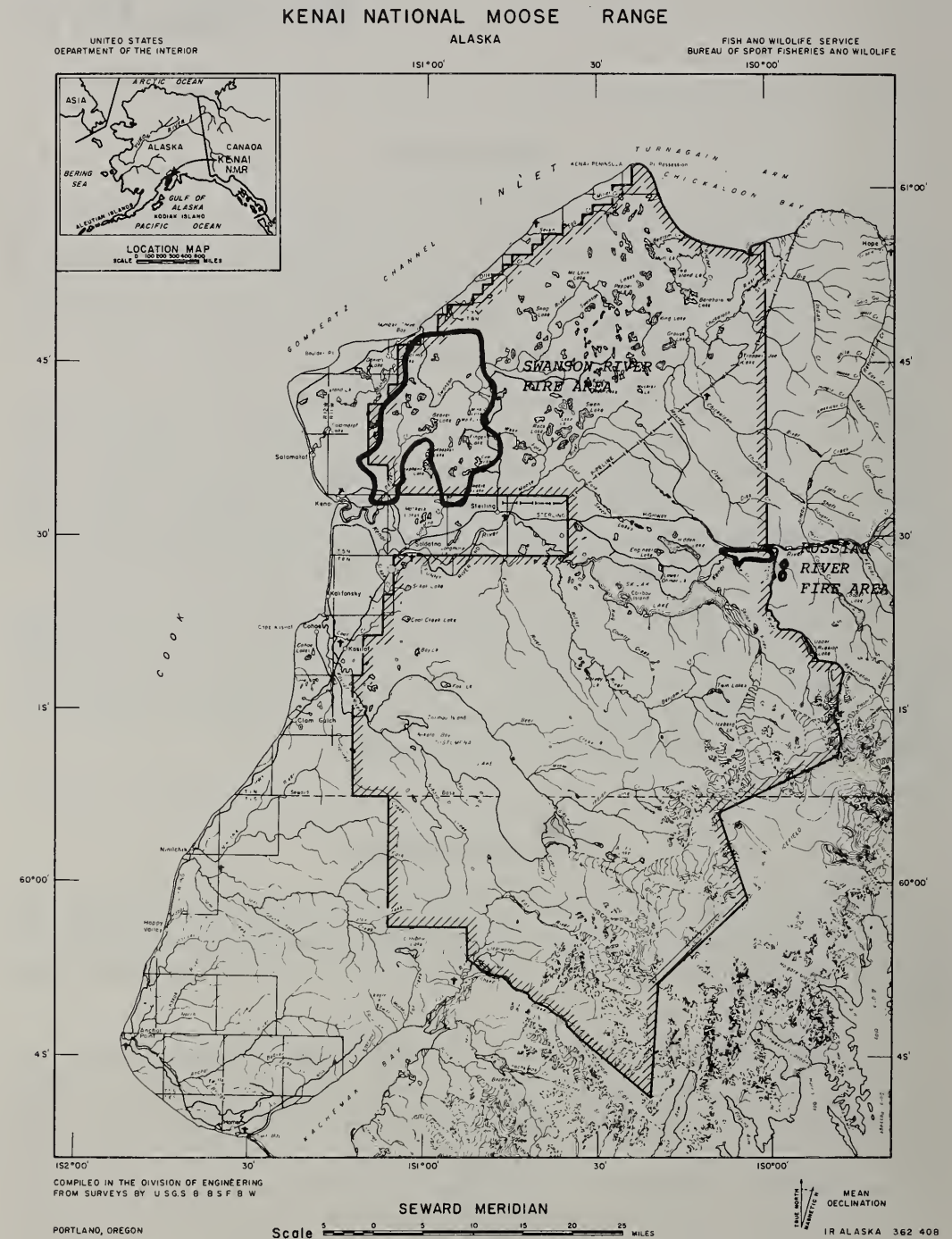


Figure 1.—Swanson-Russian Rivers fire areas.

The Swanson River fire began on August 3 and was contained and in the process of mopup on August 4, when again, high winds from the southwest with velocities of 20-25 knots reactivated the fire causing it to crown and spread 5 miles to the northeast. In subsequent days, a similar pattern followed, with high, gusty winds up to 40 knots changing the direction of the fire and pushing it on new courses with runs of 11 to 14 miles until calming winds allowed it to be brought under control on August 28.

The fire burned 86,000 acres--83,000 of which occurred on Moose Range lands. Mopup continued until October 8 when the last fire crew left. "Smokes" continued to be sighted throughout the 1969-70 winter, but the fire was finally declared out in May after spring breakup and after the area had been flown over by infrared scanning aircraft. Numerous "smokes" were reported during the following summer, all of which were checked out but proved to be erroneous. Apparently, accumulated carbon dust from fire-killed spruce had been dislodged by wind action and was reported as fires.

The Bureau of Land Management, through a cooperative agreement, has primary responsibility for fires on the Kenai National Moose Range and fought the fire to the "bitter end." At the height of the fire, 30 helicopters, 79 pumpers, 100 dozer tractors, and over 4,000 men fought the fire. With 731,000 gallons of fire retardant dropped, suppression costs varied from \$8 million to \$21 million, depending on who was doing the estimating and for what purpose.



Figure 2.—“Cat” constructed firebreaks.

Both fires were caused by careless campers. Though they were investigated thoroughly, no cases were made.

Mother Nature was attempting to tell us something—in critical areas, hit a fire with everything you've got before she becomes angry and takes over. Weather and wind conditions, in both cases, dictated the behavior of the fires.

Due to the high recreational, wildlife, and esthetic values of the land burned, while the fires were still in progress, it was determined to begin immediate restorative work with the cost of the initial phases added directly to the cost of the fires. This work consisted of rehabilitating firebreaks (fig. 2) constructed in suppression efforts by resspreading berms and dozed trees over exposed mineral soil, constructing water bars, terracing slopes exceeding 10 percent, and fertilizing and seeding critical areas to an annual rye grass (*Lolium multiflorum*).

There were 115 miles of “dozer” constructed fireline reworked, totaling 1,000 acres in the Swanson River burn (fig. 3). The project was accomplished in 25 days under the direct supervision of the Bureau of Land Management at a cost of \$400,000. An excellent rehabilitation job was accomplished.

As a result of the unusual publicity associated with the fires, Congress appropriated supplemental funds in February 1970 for additional rehabilita-



Figure 3.—Reworked catlines totaled 115 miles.

tion work. Accordingly, the Kenai National Moose Range received \$680,000 for the balance of fiscal year 1970 and \$220,000 for fiscal year 1971.

Projects which have been completed include 13,449 acres fertilized with 33-1/3 percent ammonium nitrate and seeded to an annual rye grass to prevent sheet and gully erosion on slopes over 10 percent (fig. 4). Fertilizer was applied at the rate of 100 pounds per acre and seed at 10 pounds per acre; roads were repaired and regaveled along with parking areas and campgrounds destroyed or severely damaged during fire suppression activities. Boat ramps, toilets, fire grates, tables, and log barriers were replaced wherever needed. Three LeTourneau tree crushers were purchased to knock down and crush fire-killed trees in critical areas, eliminating them as a future fire hazard and creating a buffer zone between the settled and heavily industrialized area to the south and west of the Moose Range (fig. 5), as well as providing favorable wildlife habitat.

These machines are diesel-electric with individual electric motors powering each of three large shearing drums. Each crusher had "bugs" to be "ironed out." but, despite late arrival of the machines, major breakdowns, and a possible occupational health hazard (which shut down the project for 1 month during evaluation), 10,000 acres of fire-killed trees have been worked. An additional 20,000 acres is programed to be worked.



Figure 4.—A total of 13,449 acres were aerially fertilized and seeded to an annual rye grass.



Figure 5.—Three LeTourneau tree crushers were purchased to knock down and crush fire-killed trees.

Impact of Fire on Vegetation, Wildlife, and Recreation

VEGETATION

The Swanson River fire burned in stands of every major type of vegetation represented in the Kenai lowlands. These include black spruce and white spruce, birch, aspen, their mixtures, and the various bog types.

The dense spruce stands provided excellent fuel and carried the fire when the wind reached 15-20 knots. When the fire was running as in the evening of August 7, an area 1½ miles long ignited at one time. Burned needles and leaves were carried over 50 miles beyond the fire by the strong winds.

When the fire was carried through spruce stands, it killed all the above-ground portions of plants. Some large areas within these stands were burned to mineral soil.

The black spruce retains its cones and has a plentiful supply of seed to spread following fire. No doubt this has occurred in the Swanson River fire as it did in the 1947 burn.

In hardwood stands of birch and aspen, the fire burned into the thick dry duff around the bases of the trees. In many cases, the fire consumed enough of the shallow root system to allow the trees to be easily uprooted by the wind. In other cases, the trees were killed or weakened but remained standing.

The birch trees in this area tend to have seed crops every year. The trees had a good crop in the fall after the fire. The seeds from birch are distributed at intervals throughout the winter and can be observed in large numbers following winter rains. No doubt, snow conditions (such as crust) and wind velocities are largely responsible for distances seeds are distributed. Probably portions of the burn area will come back into dense stands of birch as have areas in the 1947 burn.

The tree crushers are laying low the fire-killed stands, primarily black spruce. These stands are of pole-size trees and have no significant salvage market. Some are being used locally for fence poles and posts. We feel that the tree crushers are doing a satisfactory job. The diesel-electric system of power is new to all of us. The time lost due to breakdowns has been significant but apparently not a result of our inexperience or lack of training.

After the crushers make one pass over an area, most of the material is on or near the ground. All of the fire-killed trees do not fall forward in front of the machines as living trees would. For this reason, the crushing is not as uniform as if the machines were working in green stands. If a third pass is made over an area by the crushers, all of the big material is either on or below the ground surface. Most of these stands tend to be on fairly level ground.

When hills or ridges are too steep for efficient operation, those particular portions of the stands are left to "break up" the monotype left by the machines. Also, most of the live hardwood trees in these stands are left for seed source and esthetics.

In contrast to a black and brown junglelike mat of sticks left from the 1947 burn, the area run over by the LeTourneau tree crushers is very pleasing to the eye. The areas will soon look even better, and hiking in them will be a pleasure in contrast to hiking in the 1947 burn. There is already a significant amount of willow sprouting from decadent remnants which have been given a new lease on life with a plentiful supply of sunshine and nutrients.

The mature stands of birch and aspen, where the burning of dry duff destroyed the shallow roots, remain a problem. These areas (because the trees are large with jack-strawed boles and large root wads) will slow down the tree crushing operation but hopefully will reseed to birch.

The fire consumed the grasses and sedges along Swanson River and other streams. These areas looked extremely bad from an environmental standpoint at the time, but the bases and roots of the plants had not been destroyed, and the grasses and sedges were starting to "green up" again before the fire was demanned.

The windfallen trees in Swanson River were an important environmental problem. As the fire was demanned, the Bureau of Land Management sent crews in canoes, with helicopter support, down the river to remove these trees. Over 580 trees were removed. The following spring (1970), a Moose Range crew floated the river, removed a few additional windfalls, and cut the remaining fire-killed trees which could have fallen into the stream.

The rehabilitation of dozed lines by spreading the berm piles back over the line is of tremendous value. The material provides a more natural seed-bed and, in most cases, contains propagules. It physically prevents erosion and obstructs off-the-road vehicle use which would otherwise increase the problem of erosion.

The summer after the fire, there was a good crop of fireweed in most of the burned black spruce stands. Dense stands of horsetail were also common. The greatest crop, however, was the morel mushroom. Both people and moose consumed them in vast numbers.

WILDLIFE

Concern for the welfare of wildlife during and after the August 1969 Swanson River fire was important to many fire personnel and local residents as well as the refuge staff. Numerous inquiries about the status of the resident moose population and other wildlife directly affected by this fire were common.

A wildlife observation report form was distributed to pilots and crew leaders, and several were posted at central dispatch locations. These forms requested details of any wildlife observed in and near the fire area. A special request for knowledge concerning dead wildlife was included, but the response was nil. Not only did most report forms remain blank, but personal contacts with the firefighters, line bosses, and helicopter pilots generally resulted with negative responses. A few comments indicating losses of moose or black bear at several isolated locations were investigated without positive results. One crew leader indicated he had observed the fire-singed side of a black bear and of one moose. During an aerial survey, only one moose skeleton was observed, to my knowledge, immediately south of the Swanson River, near the fire origin. This animal may or may not have been a fire casualty.

On August 12, a noticeable number of dead fish were observed along the lower 8 or 10 miles of the Swanson River. Earlier reports of the arrival of salmon proceeding upstream indicated many fish were jumping wildly in and out of the water and thrashing savagely about. Soon after passage of the fire front and when the fire boss approved canoe travel, a river survey was conducted by Alaska Department of Fish and Game Fishery biologists. Although 501 dead adult salmon were counted, the kill probably exceeded 700 adults. Dead juvenile salmon and rainbow trout were too numerous to count. Water samples were collected during the survey to help determine the cause of the die-off but were without positive clues although the samples

indicated high carbonate levels.

Nearly 235,000 gallons of Phoschek fire retardant had been air dropped by August 11; another 46,000 gallons followed the next day, much of it deposited near the Swanson River and its tributaries.

Despite the severity of the salmon die-off, a large escapement was realized. Ocean-fresh salmon moved into the Swanson River within 4 days after the die-off was first recorded. On August 24, more than 300 salmon were observed 2 miles upstream. Apparently, whatever had been killing the fish was no longer present at a toxic level. Subsequent surveys indicated only the early arriving silver salmon were affected.

Some aerial observations of wildlife movements and activities were recorded. At no time were moose observed, either singly or in groups, moving hurriedly out of the path of the approaching fire. The fire area actually contained a relatively small moose population. Hours and even days of smoke and associated firefighting activities had probably resulted in substantial wildlife movements from the area prior to any immediate danger.

During one spectacular fire run to the north, we observed the fire front traveling 2.5 to 3 miles per hour; light debris was blown one-half to three-fourths of a mile ahead of this front, and it quickly ignited the dry grass and other fuels in which it fell. Several passes were flown along the extended flanks of the fire without sighting harried wildlife.

At one small lake (one-eighth of a mile wide), a swan family with two cygnets was sighted in the water and a moose was feeding near the shoreline while the spruce trees torched along the opposite shoreline and went up in flames.

A swan pair with three cygnets was observed several days on Cow Lake in heavy smoke during periods of active fire around the lake. This family moved from one end of the lake to the other away from the burn but did not leave the lake although all birds had fledged.

One black bear with three cubs was sighted near Doroshin Lake surrounded by fire on three sides and moving eastward across an open muskeg away from the fire. She was highly excited, but we were unable to determine whether the fire and smoke or two passes of the aircraft had contributed to her actions.

A small group of nine to 18 caribou have resided 2 miles north of the Kenai Municipal airport for several years. At one point, when the fire had reached south along Beaver Creek and west to an aircraft radio navigational facility, a group of caribou was observed lying in the open, low vegetation of that area completely surrounded by the burning fire. Later that day, the animals were again moving westward without apparent harm.

Undoubtedly, the fire took its toll of the smaller animals. Red squirrel, snowshoe hare, voles, shrews, and some birds (small bird skulls were found along the Swanson River) were directly affected.

A study of small mammals conducted by Larry Ellison¹ near Finger Lakes revealed some enlightening information. Immediately after the fire, dead voles were found in the smoldering ashes. But a year after the fire, numbers of voles seemed to be nearly equal inside and outside the burn, although numbers of shrews may have been fewer in parts of the burn. The insectivorous diet of shrews might make them more susceptible to habitat disturbances by fire.

Mr. Ellison believed traps set deeper inside the perimeter of a burned area might have shown a more significant effect of fire on voles. However, the fire left many islands of unburned habitat throughout the burn. Apparently, dozing of fire lanes (up to 50 yards wide) disturbed the habitat of small mammals more than did the fire. Dozing uprooted trees, removed much of the organic matter, and left few hiding places for small mammals. The fire, in contrast, left much cover in the form of tangles of roots of standing trees and charred organic matter.

Continuing a 5-year study of spruce grouse at Finger Lakes, Mr. Ellison² noted on one 4-square-mile plot, only 18 broods were in the burned fraction in 1970, compared with 41 on the same area in 1969. Apparently, the fire had reduced the carrying capacity for grouse broods by 56 percent.

Frequently, broods were found in sites totally burned, i.e., in ashes. No food was available, so the birds were apparently just moving through such areas, which represented a very small portion of the burn (less than 10 percent). Regrowth of vegetation has been rapid over most of the burn. One reliable report was received of a hen nesting 200 yards inside the burn in ashes under a charred log.

During July, 10 adult and five yearling hens were identified inside the burn, and 11 adults and 12 juveniles outside. Data of movement of four hens with broods which were sighted three to eight times each during the past year also suggested adult hens returned to the burn after being forced out by the fire. Movement of a fifth adult hen suggested the opposite—that after the fire forced her out of former home range, she moved into unburned habitat to raise her brood.

Nests of the trumpeter swan at Mink Creek Lake and Beaver Lake were re-established during the spring of 1970. Although their surroundings remained fire scarred, seven cygnets hatched at Mink Creek Lake and one at Beaver Lake.

Today, tracks and sightings indicate few moose within the burn. Some have passed directly through, a few remain near the browse source at Beaver Lake, and some animals are within the Swanson River oilfield area.

¹L. N. Ellison. *Small mammal study in Swanson River burn, Kenai National Moose Range.* (Unpublished report on file at Kenai National Moose Range.)

²L. N. Ellison. *Spruce grouse reproduction for 1970 and over-winter survival for 1969-70, Kenai National Moose Range.* (Unpublished report on file at Kenai National Moose Range.)

RECREATION

There were two main recreational losses—direct loss in visitor use due to closures and a long-term (20-year) loss in recreational land values.

The direct loss is figured according to the value of \$21 per visitor day, as calculated by Dr. Steinhoff.³

The long term is prorated over a 20-year period, assuming a normal 4-percent appreciation in land values. The land value lost over the next 20 years amounts to \$424 per acre. These figures are also extrapolated from Dr. Steinhoff's report.

I. Visitor use loss

1. Russian River fire		
Closed to public use, 6/14 - 7/3/69		
Estimated 50,000 visits lost		
2.5 visits equal 1 visitor day		
1 visitor day equals \$21		
$\frac{50,000}{2.5}$ equals 20,000 x 21 equals		<u>\$420,000</u>
2. Swanson River fire		
Closed to public use 8/3 - 9/1/69		
Estimated 80,000 visits lost		
2.5 visits equal 1 visitor day		
1 visitor day equals \$21		
$\frac{80,000}{2.5}$ equals 32,000 x 21 equals		<u>\$672,000</u>
Subtotal		\$1,092,000

II. Recreational value lost

Recreational value of Moose Range land equals \$39 per acre
20 years to restore
80-percent loss equals \$31.20 per acre

1. Swanson River fire	
\$31.20 x 13.59 equals \$424 per acre	
424 x 73,865 equals	<u>\$31,318,760</u>
2. Russian River fire	
\$31.20 x 13.59 equals \$424 per acre	
424 x 2,300 equals	<u>\$975,200</u>
Subtotal	\$32,293,960
Total recreational loss	\$33,385,960

³H. W. Steinhoff. *Values of wildlife and related recreation on the Kenai National Moose Range.* (Unpublished report on file at Kenai National Moose Range.)

There probably is a short-term reduction in visitor use due to the publicity these fires received. In other words, some people will probably avoid these areas if they know they are burned. On the other hand, some people may be attracted to the area to see the results of a forest fire. The numbers will probably balance out, although the length of stay may be reduced in the fire areas for a few years.

The only constructed recreational facilities that actually burned were Sunken Island Lake, Mosquito Lake trail, Forest Lake trail, and part of Surprise Creek trail. These areas normally do not receive heavy public use. Beaver, Finger, and Elephant Lakes, with high recreational potential, were severely damaged during the fire.

At Kenai-Russian River and several waysides, the burn can be seen from the camping areas, but the camping areas are not affected. The esthetic value is reduced, but this probably has little effect on public use.

According to Dr. Steinhoff, the visitors valued the Russian River area the highest of all Moose Range lands. The users indicated this area should be allocated 30.7 percent of the total management effort. The Swanson River area was valued at 16.7 percent of the total. The refuge users placed these two areas at 47.4 percent of the total value of the Moose Range for recreational uses, although these areas occupy less than 15 percent of the total land area.

One of the reasons the people place such a high value on the Russian River area is the salmon fishery. Each year, thousands of people (average 15,000 fisherman days) crowd into a 1-mile stretch of the Kenai-Russian rivers. An average of 10,000 salmon are taken annually.

There is reason for concern when considering only the salmon resources. Since this area is mountainous, has a loess soil, and is susceptible to erosion, there was a possibility of siltation of the salmon streams. For this reason, all dozed trails were rehabilitated, seeded, and fertilized, and the total burned area was seeded and fertilized. To date, there has been no reduction in salmon fishing due to the fire.

There are several recreational benefits derived from the fires, some with immediate returns:

During the summer of 1970, the Swanson River fire area produced one of the most lush crops of morel mushrooms ever seen in this area. People were attracted from far and wide to take advantage of this bonanza—2,320 people are estimated to have spent 6,040 hours picking mushrooms. There is a reason to believe that mushroom picking should be good for the next few years but will gradually decrease as the vegetation grows more dense.

In the next 3 to 5 years, moose browse will have regenerated. For the next 20 years, browse should continue to improve. This will attract many hunters and sightseers to the area as did the 1947 burn. Over a 20-year period, we can expect a gain in public use that will offset the immediate loss in use during the fire closures.

The land will become more valuable for moose, partially offsetting the long-term recreational and esthetic loss over the next 20 years. However, it will take much more than 20 years to bring the stands back to what they were before the fire. Probably the recreational-esthetic loss should be prorated over 100 years rather than 20 years.

Realistically, the recreational-esthetic loss can never be recovered, but total public use will probably increase over the next 20 years due to increased moose production and increased demand for public land for recreational purposes. People will be more willing to accept less desirable land for recreation as population pressures increase.

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Effects of fire and fire control methods in interior Alaska

Abstract

The taiga forest of interior Alaska lies within a broad zone of discontinuous permafrost. Although the gross effects of wildfire on vegetation and wildlife are fairly well known and understood, there is still a lack of knowledge on the effects of fire on interior soils and especially in permafrost soils. Serious erosion problems can occur in fine textured frozen soils with a high ice content. Fireline construction with tractors in silty permafrost soils can lead to gross gully erosion unless proper safeguards are undertaken. In some areas, catline construction has been estimated to have caused more erosion in the past than the actual effects of the fires.

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The effects of wildfire on subarctic ecosystems are imperfectly understood at best.

The intent of this paper is to explore some of the more visible gross effects of fire and more specifically the effects on permafrost soils. I would like to further explore the potential damages which can occur when traditional accepted techniques of fire control are applied on permafrost soils without modification or an appreciation of what problems may arise.

Interior Alaska is defined as that area lying between the Alaska and Brooks Ranges and from the Canadian border to the coastal tundra lowlands on the shores of the Bering Sea. This region includes the broad flat valleys of the Yukon and Kuskokwim Rivers and the adjacent highland areas. Permafrost is discontinuous throughout the area and occurs in unpredictable patterns. Most of the lightning- and man-caused wildfires are concentrated in this region. Climate is continental—long, cold winters and short, warm summers.

As is to be expected, interior Alaska supports a variety of vegetative types and associated wildlife species. A few excellent studies of the effects of wildfire on some of the more economically important vegetative types and wildlife species have been conducted in subarctic areas.

Palmer (3) in Alaska and Scotter (4) in Saskatchewan reported on the effects of fire on caribou lichen range. Their findings are similar in indicating

that lichens are slow to recover after fire, whether located in the open spruce forest or in tundra-alpine areas. Pioneer lichen species may return in 20-50 years, and an additional 100 years or more may pass before the preferred climax lichens again predominate.

Lutz (2) has described the gross effects of fire on most of the forest types found in interior Alaska. Spencer and Hakala (5) have reported on the pattern of forest succession after fire on the Kenai Peninsula and the effects of this succession on moose populations.

Fire control officials speak in terms of fuel types which are in many cases analogous to the plant associations of the biologists. Some of the more common fuel types in interior Alaska are the hardwoods (birch, aspen, cottonwood), the mixed hardwood-spruce, spruce, black spruce-bog, muskeg, and alpine or tundra.

Wildlife species vary widely in their habitat requirements. Some species may be found throughout a broad range of vegetative types, others with narrow habitat requirements may be confined to specific vegetative types which meet the species' needs. Changes in vegetative types, whether caused by fire, other disturbance, or succession, will affect either the capability of the site to support a particular wildlife species or the capability to support the same numbers of a particular species.

Little is known, however, about the factors which influence or govern the rate of recovery and the sequence of plant succession on a given site after mass destruction of vegetation by wildfire under various intensities of burn. Unknown, too, are the effects of fire on the small birds and mammals. For example, how long does it take for small rodents to reinvade the center of a 10-acre burn? A 1,000-acre burn? A 50,000-acre burn?

Even more of a mystery is the effect of large wildfires on water quality and soils in this region of the subarctic. Lotspeich et al. (1) reported on the effects of fire on water quality on one fire that burned in the Tanana Hills. Much more needs to be done, especially in a controlled situation where water quality is monitored before as well as after a fire.

Maintenance of high water quality is essential in watersheds for domestic and recreational use. Fire-caused siltation in anadromous fish spawning areas could have disastrous effects. We know that in some cases siltation caused by fire or fire control methods have affected some streams. We do not know how long the effects last nor how soon the waters can cleanse themselves of silt deposited on gravel beds.

Lotspeich et al. reported that the only evidence of erosion on the fire studied was caused by catline construction and that this erosion was capable of causing long-lasting damage to the aquatic ecosystems. Our own observations tend to confirm that most of the fire erosion problems stem from catline construction, but we have also noted some significant soil erosion in permafrost soils not associated with the construction of firelines. How much of this erosion eventually enters the stream courses is unknown.

Our observations indicate that the most critical factors governing the destructive effects of fire and fireline construction on soil erosion are the presence or absence of permafrost and the degree of slope. Knowledge of the properties of permafrost is essential to minimize mass soil wastage and erosion even where encountered on very gentle slopes.

Permafrost may vary in thickness from a few inches to several hundreds of feet. The upper surface of the permafrost may lie immediately below the duff layer or several feet below the surface under the active soil layer. The active layer undergoes seasonal thawing and freezing. Texture can vary from coarse sand and gravel to fine silts and clays. Ice content varies widely but is generally higher in the finer textured soils. Pure ice lenses are commonly found in silty permafrost. Temperature may vary from just below freezing to several degrees colder.

Temperature can be a critical factor. Permafrost at or close to the freezing point is much less tolerant of surface disturbance. In some cases, mere compression of the insulating surface vegetation can lead to melting of the ice.

Erosion has been noted on burned-over slopes underlain by silty permafrost. Apparently, absorption of solar heat by the fire-blackened surface was sufficient to start melting the permafrost. The high water content after melting created a heavy silt mud. The weight of the mud was sufficient to overcome the forces of friction and inertia to slip over the depressed permafrost surface and flow downslope.

In another area, the melting of an ice lens located close to the surface created a "blow out," the mass downward movement of a portion of a gentle slope.

None of these areas had been disturbed in any other way except by fire. Even more dramatic are the effects of some of our fire control methods on soil movements in permafrost areas.

During the years 1966-70, interior Alaska was subjected to multiple large fire occurrences. Drought conditions made control difficult if not impossible. Bulldozers were used wherever and whenever available to assist in control operations.

The objective of fireline construction was to remove all burnable material from the path of the fire. In permafrost areas, this involved removing the entire insulating vegetative layer which led to very rapid melting of the permafrost. The berms thrown to either side of the catline created effective artificial channels. To compound the problem further, the lines were tied in directly to the closest body of water for more effective line construction.

The conditions were ideal for an erosion problem resulting in siltation of streams. That is exactly what happened. In some areas underlain by deep silt permafrost soils, gullies 20-30 feet deep were created in just 2 years. In most cases, the problems of erosion from catlines far exceeded the problems of erosion throughout the remainder of the burned-over areas.

Forbs and grasses rapidly invade undisturbed burned-over areas. Fairly good ground coverage is usually attained within 2 years after a burn, even an extensive burn. Areas of previously frozen silts exposed by disturbance take much longer to develop a stabilizing ground cover. The silts are relatively sterile and are subject to excessive drying, both of which delay recovery.

Not only did the catlines cause stream siltation, they also created relatively persistent erosion problem areas for longer periods after the burn than the remainder of the burned-over area.

No criticism is intended in describing the damages caused by tractor constructed firelines. None of us were capable of foreseeing the degree to which problems would develop, and no thought was given to the actions which could be taken to reduce or eliminate erosion from the cat trails.

Blanket condemnation of the use of bulldozers in fireline construction is not appropriate either. In some cases, the use of bulldozers is the only effective way to save life and property in a wildfire situation. The fire boss is a trained expert in fighting fires, and we should not tie his hands by disallowing the use of one of his most effective tools.

I am suggesting that fire bosses be trained to recognize that there are special problems associated with the use of heavy equipment when fighting wildfires in permafrost areas. He should be taught that there are techniques to prevent or minimize erosion which can be used during actual construction of the lines. There are actions which he can take when the fire is controlled and equipment is still available on the fireline which can assist materially in preventing erosion and hastening rehabilitation.

Above all, he should have expert backup which he can call upon to assist him in designing measures to prevent erosion without interference to his main job of putting the fire out. It is up to agency management to insure that this expertise is available when needed.

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Catline rehabilitation and restoration

Abstract

Severe erosion has resulted in the past from bulldozer-constructed firelines in permafrost terrain. In an attempt to reduce erosion and gullyng, several water-barring techniques and seeding treatments were tested on permafrost and nonpermafrost catlines. Standard water bars and berm dikes constructed at 30- to 50-yard intervals on sloping terrain were effective in reducing erosion. Vegetative check dams on permafrost soils were ineffective. Seed growth was more successful on permafrost than on nonpermafrost soils. Fertilized lines resulted in better seed success than unfertilized lines.

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Erosion problems resulting from use of cats on fires has generated rehabilitation studies designed to provide information useful in catline restoration projects. Several types of water-barring techniques and seeding treatments have been tested. The following water-barring methods were evaluated for effectiveness:

Standard Water Bar—Permafrost Soil

Water-bar construction using solid and organic material at approximately 50-yard intervals on sloping terrain was effective on permafrost soils. Water was diverted into undisturbed vegetation adjacent to catlines. This work should be completed immediately after a fire prior to severe permafrost melt, which commences almost immediately after vegetative mat removal (fig. 1).

Standard Water Bar—Nonpermafrost Soil

Water bars on nonpermafrost soils were effective in decreasing erosion damages. Water bars are necessary in these soils when any degree of slope is present. Erosion is usually not as rapid and dramatic the first season or two as on permafrost areas. Past observations, however, have pointed out that severe erosion on nonpermafrost soils can occur when left untreated. Prefer-

bly, water-bar construction should take place immediately after the fire. However, delay in construction is not as critical as on permafrost soils, and barring could be done a few weeks after the burn without severe effects provided heavy rainfalls do not occur.

Berm Dikes or Dams—Permafrost Soil

Construction of berm dikes at 35- to 100-yard intervals along approximately 10 miles of catlines was accomplished on Fire OE7 adjacent to the Taylor Highway. Diking was done in October 1968 after the ground had frozen and cats could work without getting stuck.

Berm dikes were effective in minimizing erosion. Ponding of water was common above many of these dikes. This type of construction should be completed immediately after the fire is out. Leaving this type of work until late fall can generate problems (cold temperatures, deep snows, closed roads, unfrozen soil pockets, deep erosion channels, etc.).

Vegetative Check Dams—Permafrost Soil

Check dams constructed from logs and branches on ALPHA trails near Fairbanks were completed by the military in the summer of 1969. These dams, located at approximately 100-yard intervals, were an ineffective erosion technique on permafrost soils. Ice melt underneath these dams created severe erosion channels. Deep deposits of mud were observed on the



Figure 1.—Effective water bar. Photo taken in June.

Elliott Highway, and State Highway Department personnel used graders to remove these deposits. The problem became so troublesome that cats were required to construct berm dikes at close spacing along this trail. Results were effective and erosion was nearly stopped. Although use of vegetative check dams on permafrost soils is ineffective, their use on nonpermafrost soils can effectively deter erosion.

Example of this can be observed along the Livingood to Yukon River haul road.

In addition to water-barring tests, the following trial seeding project has been designed to provide rehabilitation information:

King Creek Fire Rehabilitation Project

Experimental rehabilitation treatments involving applications of seed and fertilizer on King Creek Fire catlines were started in the fall of 1969. The work involved a variety of seeding treatments to test fall and spring application on permafrost and nonpermafrost soils. Portions of lines seeded in fall and spring were fertilized to test response of seed to fertilization. The following treatments were completed:

FALL TREATMENT

Approximately 2 miles of catlines, involving 1 mile of permafrost and 1 mile of nonpermafrost soils, were seeded by cyclone hand seeders on October 4, 1969. The following grass mixture was applied:

200 pounds Manchar smooth brome
100 pounds Kentucky blue grass
300 pounds mixture applied at 40 pounds per acre

No snow was on the ground during application. October was selected as an ideal seeding time since cold temperatures persisted which eliminated any possibility of seed germination resulting in frost kill of seedlings.

SPRING TREATMENT

Two miles of catlines involving 1 mile of permafrost and 1 mile of nonpermafrost soils were seeded onto snow surfaces by helicopter on April 20, 1970. The following grass mixture was applied:

60 pounds Reed canary grass
60 pounds timothy
60 pounds sweet clover mix (white and yellow)
60 pounds rye
60 pounds Manchar smooth brome
20 pounds Kentucky blue grass
320 pounds mixture applied at 40 pounds per acre

Snow depth averaged 12-18 inches which upon melting provided moisture for the seed and water rivulets to aid in covering the seed with soil.

A fertilizer application of 300 pounds per acre was applied by helicopter on April 20, 1970, onto fall and spring seeded lines. A 20-20-10 pellet-form fertilizer was used as recommended after soil analysis by the University of Alaska Extension Service.

Field observations were made in June and in August 1970 to measure seeding success after one growing season. The following information was gathered from trial seeding plots:



Figure 2.—Permafrost area—fall seeded, fertilized. Photo taken in June at start of germination.

Permafrost plot—fall seeded, fertilized.—Germination of seed was well underway by June. Water-saturated soil was common due to melting and runoff of surface ice. Permafrost depths were generally less than 2 feet below the soil surface and prevented good drainage. Downhill water movement formed erosion channels in June.

Observations in August indicated good response of Manchar smooth brome on this plot. Surface water movement had decreased by August and soil was stabilizing. Kentucky blue grass response was poor. Top growth of



Figure 3.—Permafrost area—fall seeded, fertilized. Photo taken in August showing seed response.

brome was less than 8 inches. No evidence of flowering was observed among seeded species (figs. 2 and 3).

Permafrost plot—fall seeded, no fertilizer.—Seed response was fair, but heights and densities of plants were not as good as on the fertilized permafrost plot. Manchard smooth brome was the dominant grass species observed. Soils were spongy and wet in June with drying evident by mid-August. Permafrost was less than 2 feet below the soil surface.

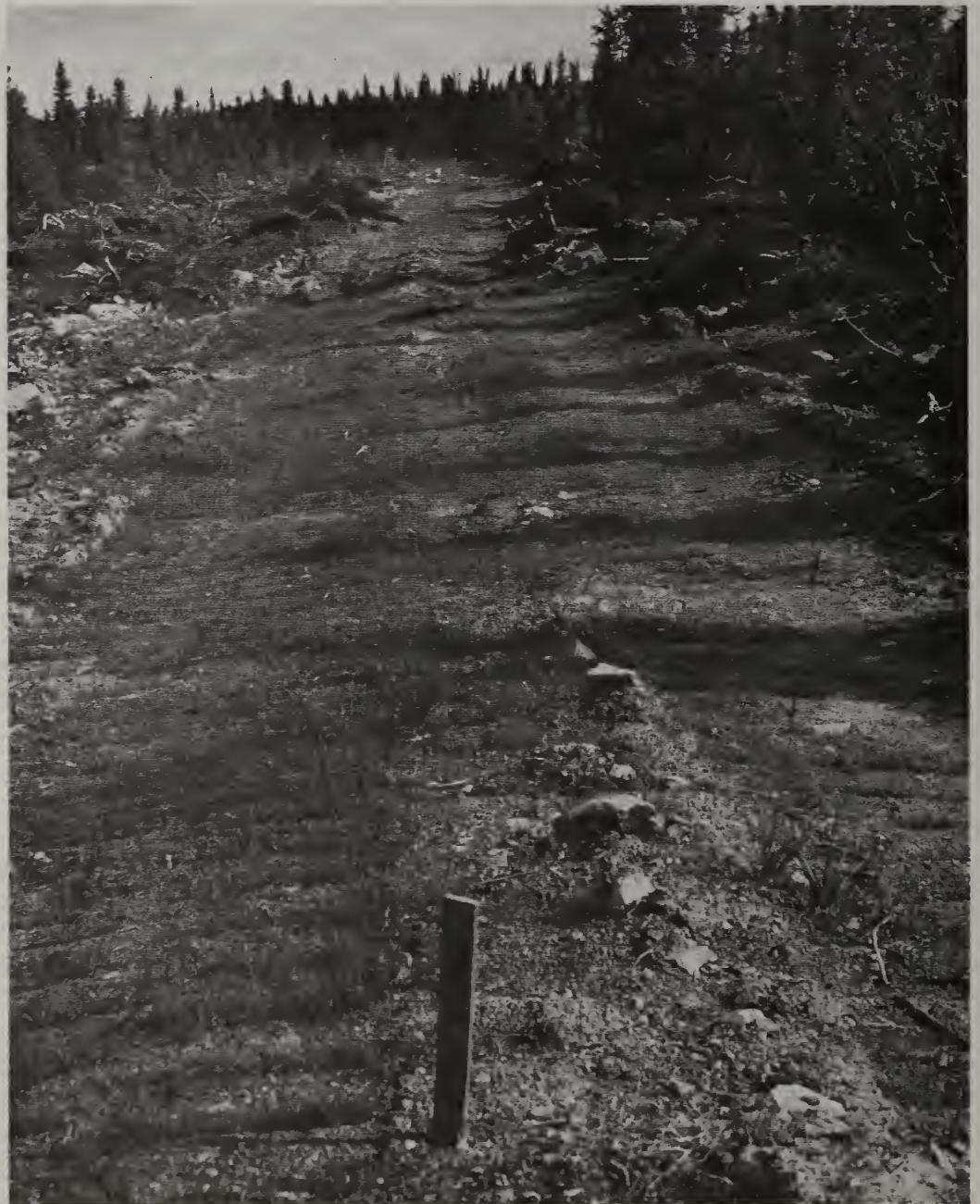


Figure 4.—Nonpermafrost area—fall seeded, fertilized. Photo taken in August of seed response.

Permafrost plot—no treatment.—Natural revegetation had started with some evidence of sedges, grasses (*Calamagrostis*, *Eriophorum*, *Equisetum*), and small mosses. Plants were small and not in sufficient abundance to effectively deter erosion. Water-saturated soils persisted on this site, and downhill movement of water occurred in mid-August.

Nonpermafrost plot—fall seeded, fertilized.—Well-drained soils with minor erosion problems were observed on this plot. Seed response (Manchar



Figure 5.—Control area—nonpermafrost location. Photo taken in August.

smooth brome) was evident mainly in cat track depressions where moisture retention and seed coverage occurred. Ungerminated seeds were common on soil surfaces between track depressions. Dominant seeded species growing was brome grass. Lack of moisture and soil coverage of seed appear to be limiting factors prohibiting good plant growth on this plot (fig. 4).

Nonpermafrost plot—fall seeded, no fertilizer.—Grass growth (brome) was fair but spotty on this study area. Plant growth occurred mainly in caterpillar track depressions. Overall success of seeding was not as effective on this plot as on fertilized areas. Soils were well drained with little evidence of erosion.

Nonpermafrost plot—no treatment.—Little or no natural revegetation was observed at two of the three established photo points. Growth of *Equisetum* was evident on the third control site where soil moisture capacity was greater. Overall examination of untreated nonpermafrost catlines indicated poor natural revegetative recovery (fig. 5).

Permafrost plot—spring seeded, fertilized.—Seed germination was good, but plant sizes were smaller on lines seeded in spring than those seeded in fall. Individual grass species were difficult to identify on spring seeded catlines due to immaturity of plants. Examination of the entire plot indicated plant densities to be greater from seed applied in fall than from seed applied in spring.

Permafrost plot—spring seeded, no fertilizer.—Size and density of plants were poorer on this unfertilized plot than on fertilized permafrost lines. Wet spongy soils persisted through mid-August on this study area with some erosion taking place.

Nonpermafrost plot—spring seeded, fertilized.—Examination of this plot indicated poor seeding success compared with the fall seeded nonpermafrost line. Brome was the dominant seeded species present. Again, grass grew best in cat track depressions.

Nonpermafrost plot—spring seeded, no fertilizer.—Growth of plants was poor on this plot compared with growth on fertilized lines. Few erosion problems were evident due to well-drained and level terrain.

General Comments

Several growing seasons will be required to adequately evaluate effectiveness of various treatments in erosion damage control. Preliminary observations after one growing season did indicate better seed response from fall than from spring-seeded lines on permafrost and nonpermafrost soils. Hand-seeded lines during fall application may have resulted in somewhat heavier seed application than from aerial treatment. Rotor wash and side winds may

have resulted in some seed landing adjacent to catlines. However, seed distribution on snow surfaces during spring seeding indicated good seed distribution where examined. Brome appeared to grow best of all species seeded.

Brome seeding rates were higher in the fall than in the spring application which also may have contributed to the rather light response from spring seeding.



Figure 6.—Erosion stabilization by seeding—permafrost area. Photo taken in August.

Seed growth was more successful on permafrost than on nonpermafrost soils (fig. 6). Lack of soil coverage of seed and absence of moisture appear to be among limiting factors on nonpermafrost soils. Drilling rather than aerial application of seed on nonpermafrost soils may result in better seeding success. Aerial or hand broadcast seeding methods would be effective for seeding permafrost soils. Fertilized lines resulted in better seeding success than unfertilized lines.

Water bars and/or berm dikes at 30- to 50-yard intervals on sloping terrain in combination with seed and fertilizer would be effective techniques in decreasing catline erosion damage.

A short history of the fire weather service and the “Federal Plan for a National Fire Weather Service”

Abstract

A short history of the fire weather service is presented with a report on progress made under the “Federal Plan for a National Fire Weather Service.” The highlights of the plan and its application to the requirements of forest and range management interests in Alaska are stressed. The services now provided are contrasted with those services that are possible under the present level of meteorological development.

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The fire weather service is one of the National Weather Service's oldest programs. As with many government services, it has had its periods of growth and stagnation, all closely related to periods of economic growth and recession and national emergencies. Currently we are maintaining the program at the level reached in fiscal year 1968.

The first record we have of any special forecast service to forestry interests was in 1913. At that time, what is now the National Weather Service was asked to provide warnings of east winds in the Columbia River Gorge. These are strong, very dry winds. The following year, wind warnings were issued during the fire season for Washington, Oregon, Idaho, and Colorado.

Beginning in 1916, all district forecast centers were authorized to issue fire weather warnings. In 1924, the first meteorologists were assigned to provide the service, one at Seattle, Washington, and one at Portland, Oregon. In 1926, a red-letter year, the first funds were provided by Congress for the fire weather service.

In 1929, the U.S. Forest Service and the California State Division of Forestry furnished a truck equipped with a radio receiver and weather instruments for use as a forecast office at large fires. The radio receiver was used to copy weather observations transmitted by Morse code from the Navy radio facility near San Francisco. This was the forerunner of the mobile fire weather units we use today. In 1937, funds became available to provide four panel delivery trucks for conversion to mobile units.

During World War II, the service was provided as best possible considering the manpower shortage and the heavy demands on the National Weather Service by the military and related agencies. Following the war, the fire weather service stagnated and even deteriorated to some extent.

By 1950, the requirement for fire weather forecasting had become acute with at least one large private association urging Congress to provide funds for expansion of the service. None were received.

During this period, some States provided aid under cooperative agreements to establish or strengthen the fire weather service at five offices.

In 1959, National Weather Service officials began working with forest and range management agencies to draw a plan for funding and providing fire weather service to all fire protection and related agencies. Our present "Federal Plan for a National Fire Weather Service" is a revision of the original plan drawn by this group.

Originally, the plan had three phases or steps, to be completed in 3 years. However, it became apparent that funds would not be made available to implement the plan in such a short period. The plan was changed, and the three phases covering the field service program were broken into seven smaller steps. Four-and-one-half of these phases or steps have been completed. In the current edition of the plan, two additional phases have been added for research activities, neither of which has been funded.

Funds for expansion of the service were first received in fiscal year 1962 and continued to be made available for several years. However, since fiscal year 1966, expansion of the service has been slower. In F.Y. 1968, four fire weather meteorologists were added. No expansion has taken place since.

At present, two permanent fire weather meteorologists are assigned to the program. This number is inadequate to cover an area the size of Alaska with its varied climatic regime. Mr. Comiskey has told me that region headquarters is planning the temporary assignment of two or possibly three meteorologists to the fire weather program, so there will be four or five meteorologists working in the Alaskan fire weather service during the 1971 fire season. This arrangement uses funds and personnel diverted from other service programs. There is no guarantee that the arrangement can be continued.

A fire weather staff of five meteorologists is considered the minimum to meet the needs of fire control agencies in Alaska. It will allow a 16-hour-day coverage for fire weather and more detailed forecasts for smaller areas. It is anticipated that the expanded staff will result in a significant increase in service and quality of the forecasts.

As the last third of the field service program covered by the Federal Plan for a National Fire Weather Service is implemented, three additional fire weather meteorologists will be added to the permanent fire weather staff at Anchorage, bringing the total to five. The temporary expansion in the service during the 1971 summer season will provide an excellent pilot program for

the permanently staffed program outlined in the national plan.

Many changes have taken place since the national plan was devised, some within the plan itself and others within the organization of the National Weather Service. In the plan, there has been considerable revision in the priority list—that is, a rearrangement of the order of implementation in the remaining phases. Alaska has been given a much higher priority for the additional personnel than is indicated in the March 1967 edition. The remainder of the plan is still valid though minor changes will be made in the next printing.

A major and very important internal change has taken place within the National Weather Service since the original plan was written. Full responsibility for the field service programs was assigned to the several region headquarters. Final decisions on the location of personnel and changes in the service program itself are now made by officials who are familiar with the operating program and are in a position to consult directly with agencies and groups using the service. The result has been a decided improvement in all the National Weather Service programs, including the fire weather service.

Another major change is one brought about by technical progress in the field of meteorology and by the requirement to make maximum use of professional personnel. During the past year or so, the National Weather Service has begun a complete reorganization of its forecast program which, stated briefly, will concentrate its forecast programs in a single office in each State. In those areas where this change has already been accomplished, results have been as good or better than expected. The effect of this move in Alaska is likely to be minimal since the Weather Service office in Anchorage has always been the forecast center for the State.

It has been suggested that a mobile fire weather unit is needed for the Alaska fire weather service. This is a small weather office, manned by a fire weather meteorologist, which is taken to the site of a fire and set up near the fire boss's quarters. The unit is equipped with two-way radio telephone, radiofacsimile, and a set of portable weather instruments. Power is provided by a small motor generator. Through the use of the communication equipment, the forecaster receives the latest weather charts and other meteorological information. These are used to prepare forecasts for briefing fire control personnel. Mobile units now in use are made from camper shells and are mounted on 1-ton pickup trucks. Such a unit would be unable to reach many of the fires in Alaska. Mr. Comiskey has recommended that an airborne unit be developed. There are several approaches to the problem. At the Boise Interagency Fire Center, an airborne unit is packaged in individual units so that it can be transported by a relatively small cargo airplane or by small helicopter. It uses a tent for sheltering the equipment and to provide quarters for the meteorologist. The boxes used for packaging the equipment become desks and worktables. Should a helicopter of sufficient lifting ability be available, possibly a complete unit in one lightweight housing would be more satisfactory.

In summary, the size of the fire weather service has remained nearly constant in recent years. We have been unable to implement any part of the plan since fiscal year 1968. We still expect the Federal plan eventually to be fully implemented with three fire weather forecasters added to the Alaska complement. These additional fire weather forecasters should assure adequate fire weather service for the forested areas of Alaska. A mobile unit, to be procured as soon as funds become available, will bring the fire weather office to the site of large fires.

A relationship between National Fire Danger Rating System spread index and time-of-day in interior Alaska

Abstract

Daily cyclic patterns in air temperature, relative humidity, and windspeed cause variations in fire behavior. A relationship between time-of-day and spread index was developed for four interior Alaska stations to predict diurnal fluctuation in fire danger for planning fire control operations.

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Introduction

Fire control planners schedule some activities on the basis of a 24-hour planning period. For example, Bureau of Land Management fire suppression operations in Alaska are governed by a policy statement that recognizes a daily planning period (3):

Our policy is to control fires during the first work period. Each district will dispatch sufficient crew to control such reported class A, B, and C fires before the start of the next burning period (1000 hours each day). For any fire that is not controlled in the first work period, the fire boss will request sufficient forces to control it before the start of the next work period.

An important planning input is fire behavior. Information relative to fire behavior throughout the 24-hour period can be useful for "calculating probabilities," a fire planning procedure widely taught, and less often used. A concept as simple as constructing fireline faster than the rate of perimeter increase may be applied. Success depends upon an ability to anticipate rate of spread and judge resistance to control, so sufficient control forces can be ordered to complete the control line. "Calculating probabilities" forces the planner to systematically consider important factors.

Fire spread, measured by the National Fire Danger Rating System (NFDRS) spread index, is only one of four phases of the basic structure of the danger rating system (fig. 1). The spread index, a part of the NFDRS, integrates the effect of several factors in terms meaningful to the fire plan-

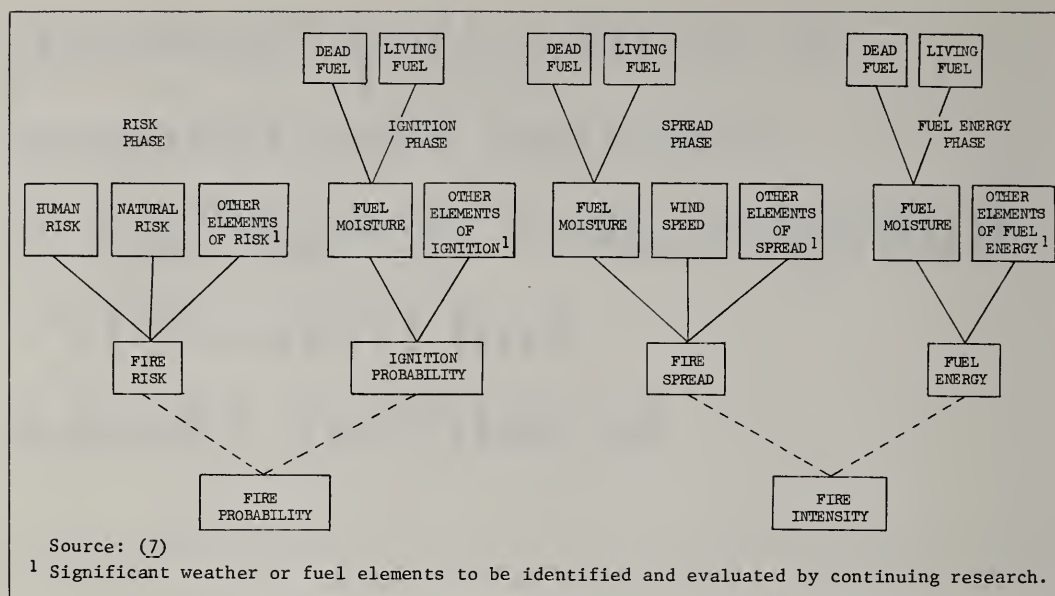


Figure 1. Basic structure of the National Fire Danger Rating System.

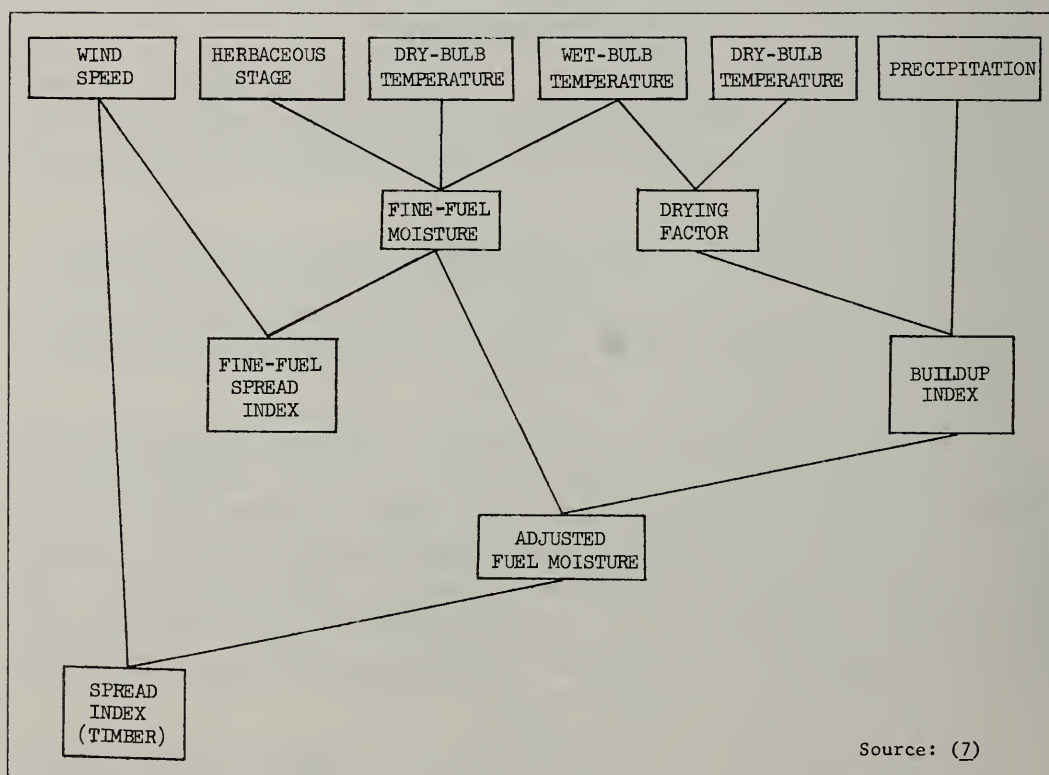


Figure 2. Components of the spread phase of the National Fire Danger Rating System used in interior Alaska.

ner. Components of the spread index, as applied in interior Alaska, are dry-bulb temperature, relative humidity, and windspeed. The spread index (fig. 2) integrates air temperature and relative humidity in a fine-fuel moisture determination and then combines fine-fuel moisture and windspeed into a fine-fuel spread index. Spread index is a number expressing the relative rate of forward movement of surface fires.

In Alaska, as elsewhere, fire control plans are based on spread index, and spread index can be assumed to follow a diurnal cycle. Spread index values are related to time-of-day in the Intermountain States (6) and in the Lake States (2). Fuel moisture percent, air temperature, relative humidity, and dewpoint, and the burning index have been shown to follow a diurnal pattern in Alaska (5). However, a relationship between NFDRS spread index and time-of-day has not been developed for Alaska. The results of a study to determine the diurnal pattern of spread index in interior Alaska are condensed in this paper.¹

The Problem

Formalizing questions about the relationship between spread index and time-of-day were helpful in designing an objective analysis procedure. (1) Are there differences in the relationship in different climatic zones? (2) Does the relationship change as the season progresses because of changes in length of day? (3) Does the relationship change on days with extreme burning conditions? The relation should be representative of days with extreme potential for fires to spread, as well as of more "normal" or average days. The following null hypotheses were established. The diurnal variations in spread index do not change with:

1. Location
2. Season
3. Magnitude of the index

Methods and Results

Local climatological data published by the National Weather Service were used as the data source for computing spread index. Summaries for Anchorage, Bethel, McGrath, and Fairbanks were obtained for April through July, 1957 through 1961. The stations are located in the transitional and continental climatic zones of Alaska (fig. 3), which are important fire zones. The months of April through July cover the maximum of both man-caused and lightning-caused fire occurrence periods (fig. 4). The years 1957 and 1959 were extreme fire years with 391 and 320 fire occurrences, and 5,049,661 and 596,574 acres burned, respectively. Only 44 fires and 5,100 acres burned in the year 1961.

¹Study results are being reported to the Graduate School, University of Montana, Missoula, in a master's thesis, "An Analysis of Diurnal Variations of National Fire Danger Rating System Spread Index in Interior Alaska."

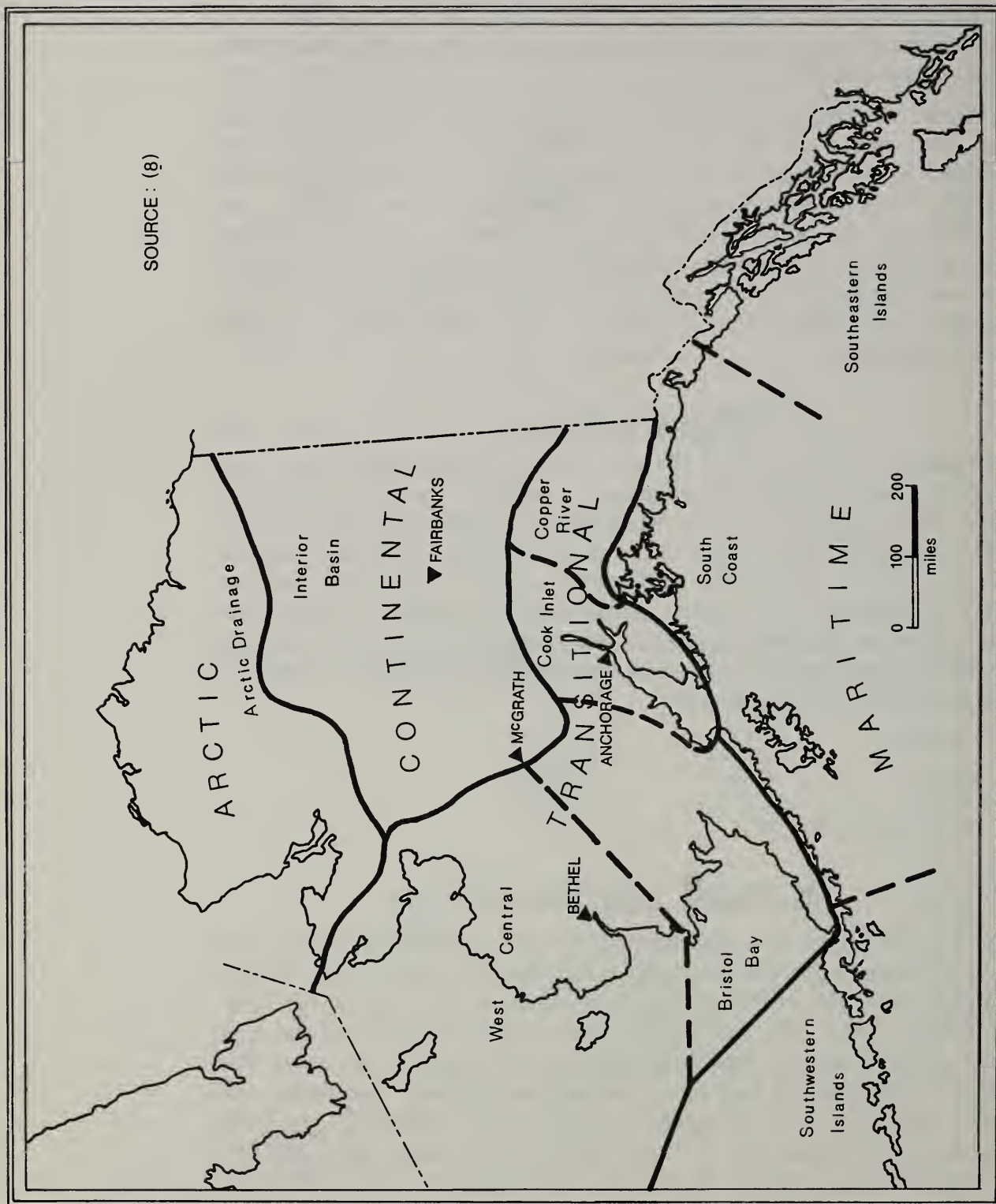


Figure 3. Map of Alaska showing climatic zones and location of stations studied.

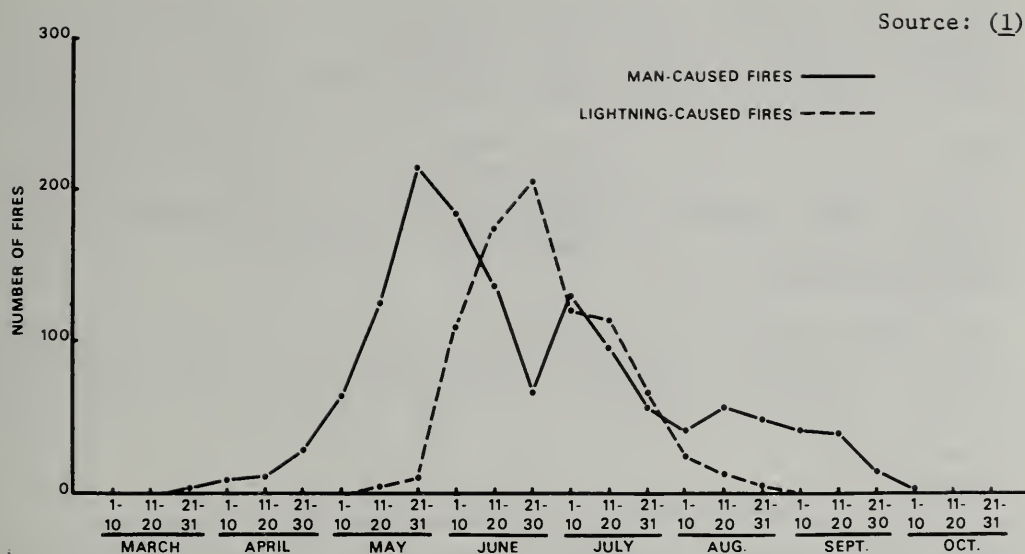


Figure 4. Number of fires by cause for 10-day periods, interior Alaska, 1956-65.

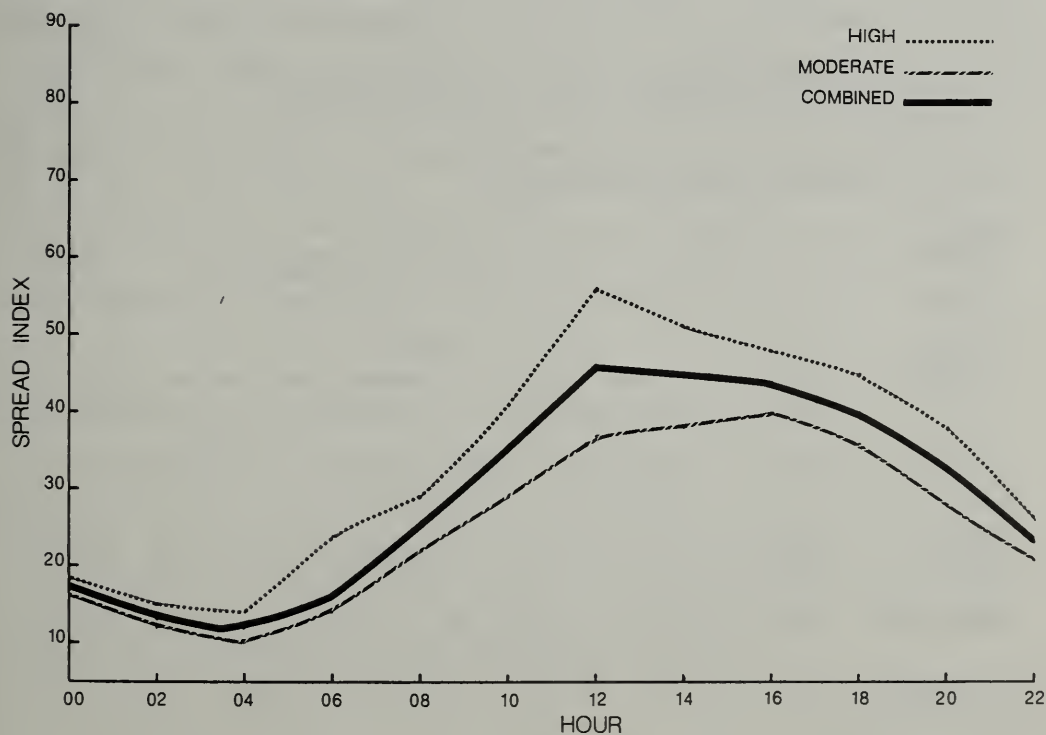


Figure 5. The relationship between spread index and time-of-day for four stations for two seasons by class-of-day.

Selection of a sample of days for developing the relationship between spread index and time-of-day was an important step. A similar study (4) in northern Idaho used settled summer days, beginning on the fifth day in July on which the burning index reached 30 or more, as the criteria for selecting sample days. The criteria helped select days with diurnal variations typical of days when fires were most likely. For similar reasons, two classes of days were arbitrarily established to select days for this study. The basis for selection was the noon spread index, and the selection criteria were (1) moderate, 30-49, and (2) high, 50 plus.

The noon spread index was computed for each day. Spread index was computed according to procedures outlined in the National Fire-Danger Rating System Handbook (7). Herbaceous stage was assumed to remain cured throughout the year in accordance with local practice. Two days were then systematically selected for each year-station-season-class category. Seasons were defined as (1) April-May and (2) June-July. Total sample size was 2 (days) x 5 (years) x 2 (seasons) x 4 (stations) x 2 (classes-of-day), or 160 days. Spread index values were computed bihourly (0000, 0200, . . . , 2200 hours) for each of the 160 sample days. Total number of observations was 160 days x 12 bihourly observations per day, or 1,920 observations. Analysis of variance was computed with spread index as the variable of interest, and hours, seasons, classes-of-day, and stations as factors.² There were no significant differences in spread index between stations, seasons, or the interactions of hours and seasons or hours and stations. This is reason to accept hypotheses 1 and 2 and conclude that there is no difference in the diurnal pattern of spread index between seasons and locations. A relationship based on these results is termed "combined" and shown in table 1 and figure 5. "Combined" means an average of the two classes-of-day.

² Years were not considered as a source of variation, and inclusion as a factor in subsequent studies may increase the sensitivity of the analysis of variance.

TABLE 1.—Bihourly spread index values for four stations and two seasons

Class-of-day ¹	Hour											
	00	02	04	06	08	10	12	14	16	18	20	22
----- Spread index -----												
High	18	15	14	19	29	41	56	51	48	45	38	26
Moderate	16	12	10	14	22	29	37	38	40	36	28	21
Combined	17	13	12	16	25	35	46	45	44	40	33	23

¹ High: Noon spread index = 50 plus.
Moderate: Noon spread index = 30-49.
Combined: An average of moderate and high.

The interaction between day class and hours was significant.³ This difference can be seen by examining the relationships of high and moderate classes in table 1 and figure 5. Spread index peaks at noon on high days and at 1600 hours on moderate days.

A sampling problem prevents interpreting the significant interaction between day class and hour as reason to reject hypothesis 3. The interaction suggests there may be a different diurnal pattern associated with the general level of the index. The selection criteria may have biased the sample toward days with spread index peaks at noon. This puts a restriction on how generally the relationships can be applied. The "high" and "moderate" curves represent the diurnal pattern only on days that fit the selection criteria.

Discussion and Conclusions

Our ability to interpret spread index in terms of natural rate of spread is quite crude. Knowing the diurnal pattern can give the theoretical insight necessary to understand fire behavior even though the numbers cannot be interpreted precisely. Interest is more in the trend of the curve than in the numerical value itself.

The relationship of spread index to time-of-day on "high" days contradicts many fire control people's assumption that spread index maximum would occur near 1600 hours on all days. The fire planner assuming that spread index will increase from noon to 1600 hours on "high" days is likely to misjudge the fire control situation.

Users of the relationships presented in this paper should keep in mind the data base from which they were derived. The curves do not represent an average or "normal" day. The curves were derived for four stations in the two climatic zones and should not be expected to hold in other zones. The curves represent the April through July portion of the fire season. Season and location results suggest the relationships may apply generally. Until such time as relationships are derived using a broader data base, it may be necessary to apply these curves. General application may be reasonable, considering that the information taken from one location, Priest River, Idaho, has been interpreted to represent the entire Intermountain States area.

The relationships should help predict fire behavior during the 24-hour period. This type of curves has broader application than planning control operations. Resource managers need fire behavior information to evaluate fire effects and to manipulate vegetative cover by prescribed use of fire. Hopefully, the relationships will also fill one of the information voids necessary to define the role of fire in the northern environment.

³ $F_{11/1728} df = 7.88$ which is significant at the 0.01 level.

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Bureau of Land Management computerized fire-danger rating system

Abstract

In 1967, the Bureau of Land Management in Alaska began producing isoline maps of buildup index by hand on a daily basis. These maps proved to be operationally valuable. In 1969, it was proposed that the isoline maps and other fire-danger ratings be produced by machine. By the middle of 1970, a complete fire-danger rating package, including isoline maps, was being machine-produced on a daily real-time basis and disseminated to a variety of users within 4 hours of observation time. This paper describes the system by which the data are processed, the form of the output, and the method of dissemination.

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The vastness of Alaska and the inaccessibility of many of its parts pose many disadvantages, but in at least one respect, there is an advantage—its vastness and inaccessibility tend to force one to make adaptations that might not be considered elsewhere.

For instance, let us consider the problem of fire detection by looking at figure 1. The area of most common occurrence of wildfire is the mainland of Alaska—approximately 600 miles north and south and the same east and west—comprising a total of 360,000 square miles. The area is too vast to consider for a conventional fire detection system. Consequently the Bureau of Land Management (BLM), which has the bulk of responsibility for fire control within Alaska, has developed a rather sophisticated system of aircraft patrol.

In addition to looking for fires, a major function of the patrol system is thunderstorm detection and followup. On certain days, the thunderstorm area is so large that a fleet of five aircraft, ranging from a Lear Jet to a Cessna 180, cannot adequately cover it.

Furthermore, if a fire was detected—say near Kobuk—the closest smoke-jumpers would be 300 miles away in Fairbanks. The closest retardant plant would be in Galena—150 miles away. The fastest retardant aircraft we now have, a PB4Y, would take 2 hours to make the round trip to the fire.

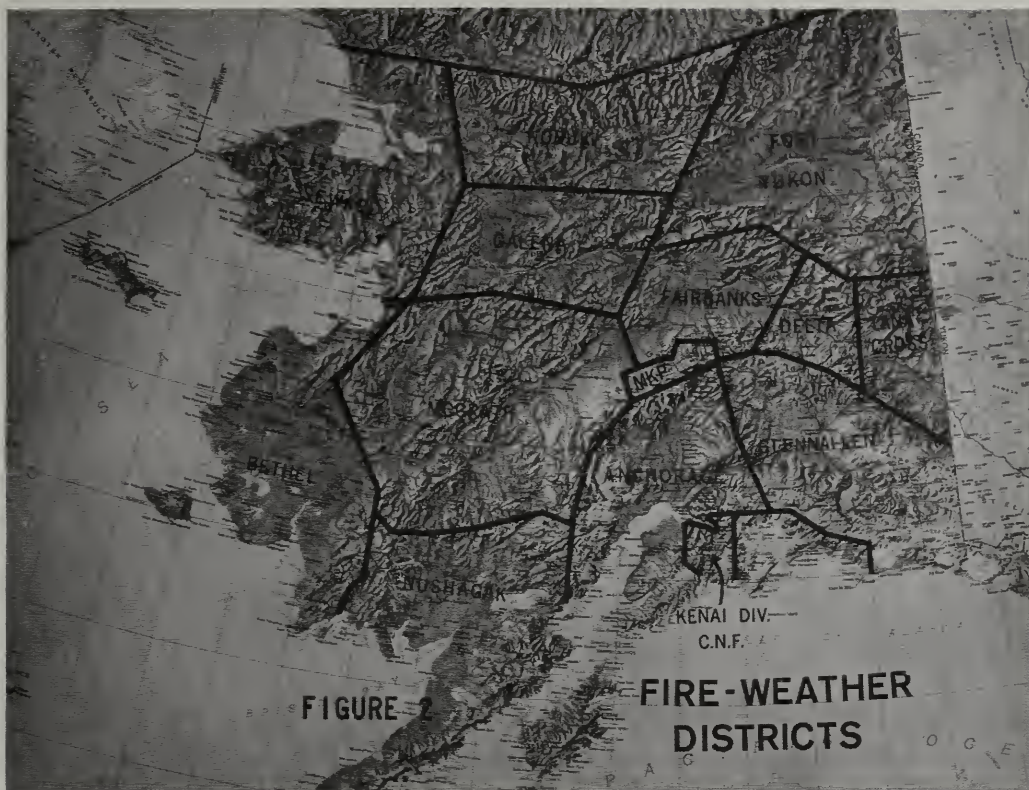
In 1970, there were only 39 permanent BLM employees available and qualified for fire duty. Consequently, 119 "seasonals" were hired last summer. Many emergency firefighters are scattered throughout the entire State in small villages with access only by plane or boat.

Pre-positioning of men and equipment is being used more and more. Pre-positioning can save millions, but it also can cost quite a bit. It is relatively easy to see that we have problems that do not exist elsewhere. These problems forced us to adapt, and one of the adaptations was the isoline map of buildup index, which evolved in the following manner.

The fire-weather unit in Alaska prepares and disseminates scheduled, specialized, thunderstorm forecasts for patrol purposes. The BLM Division of Aviation receives the forecasts via a fire-control teletype network. The patrol coordinator frequently calls the fire-weather forecaster for additional input—particularly when the thunderstorm forecast area is large.

Since there were times when it was impossible to patrol the entire thunderstorm forecast area, the problem became one of how best to reduce the patrol area (fig. 2). On numerous occasions it was suggested, by the fire-weather forecaster, that the patrol be limited to the areas of high buildup index—say 80 or higher. This suggestion brought to light a weakness in the patrol planning—there was no comprehensive depiction of the fuel moisture pattern in the State. To overcome this, the fire-weather meteorologist suggested that the BLM construct isolines of buildup index. This suggestion was adopted; and a study course was prepared and a training session was con-





ducted to familiarize BLM personnel with procedures for preparing the isoline chart, which was utilized by fire control operations beginning in the summer of 1967.

In late 1968, Lowell King of BLM proposed that the fire-danger ratings of buildup index (BUI), spread index (SI), fine fuel moisture (FFM), and condition class (CL) be handled by computer. The problem was presented to the BLM Branch of Data Processing, and a program was written and run on an experimental basis during the summer of 1969.

At that time, BLM had an in-house IBM 1130 Computer and an IBM 1627 Plotter. The programs are written in Fortran IV.

The first program, labeled WEA2, inputs the basic weather data required for fire-danger rating computations. It computes BUI, SI, FFM, and CL for individual stations, lists fire-danger ratings, lists past weather and past fire-danger ratings upon call, and recomputes all fire danger ratings from point of data addition, or correction, to latest data entry. Figure 3 shows the form of the tabulated output.

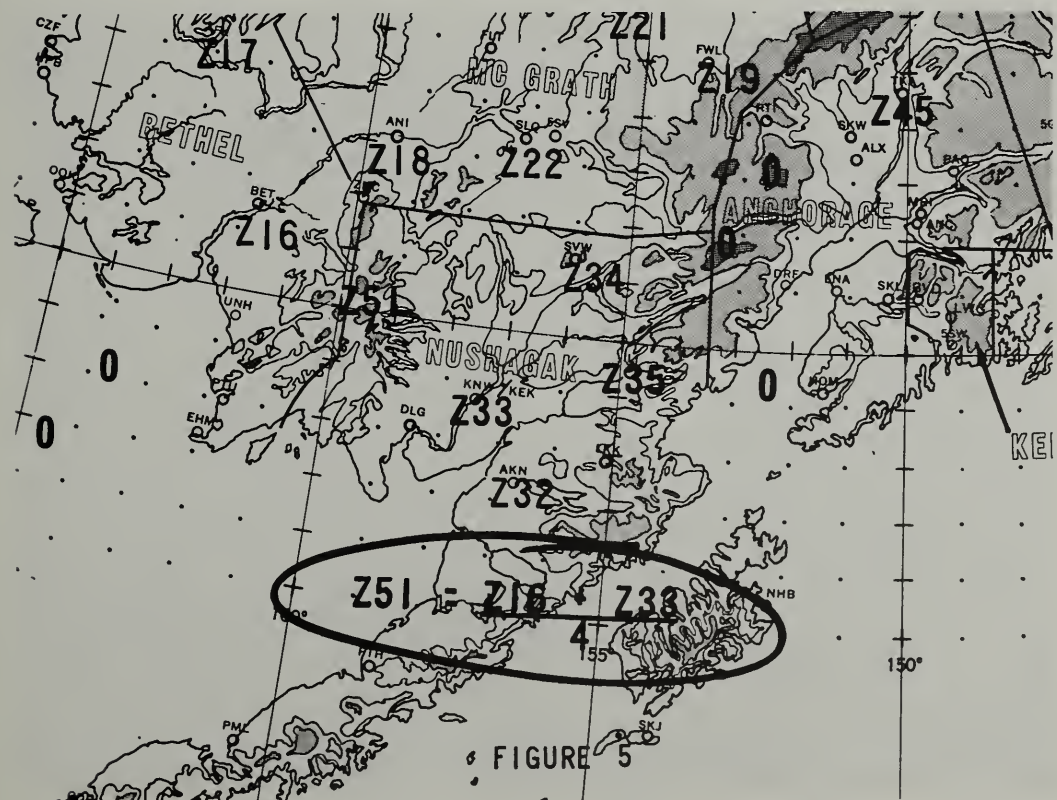
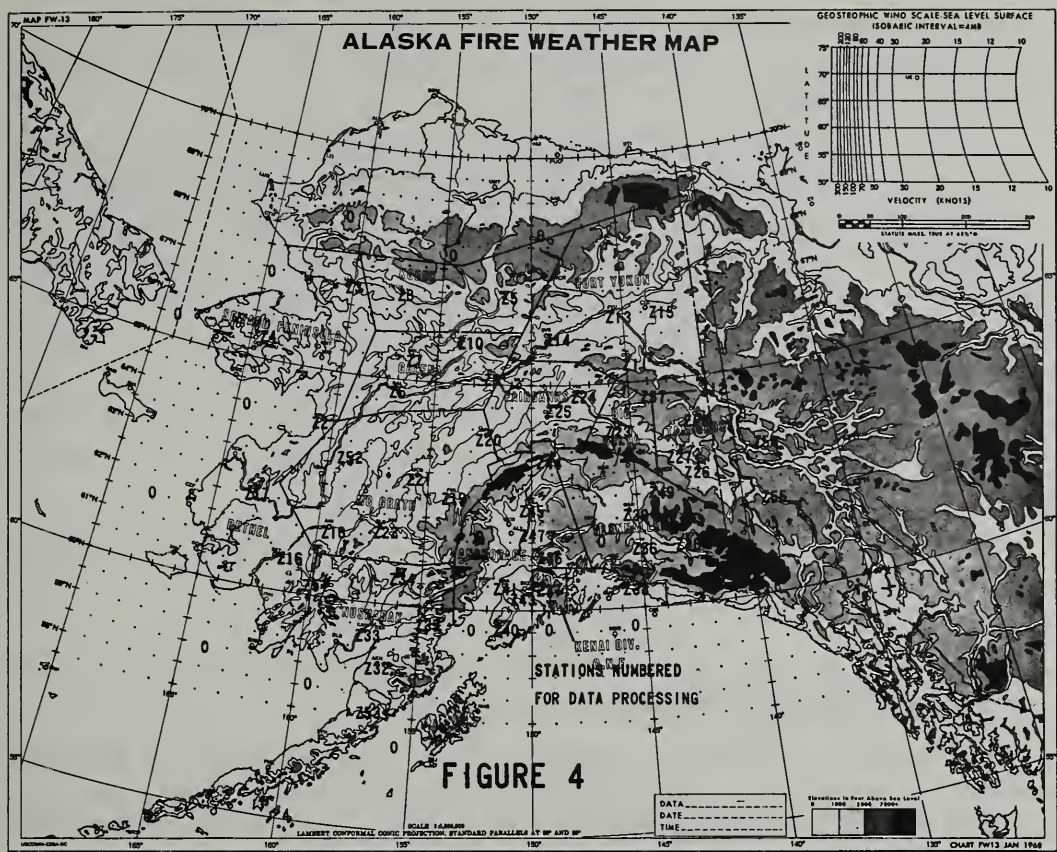
As program WEA2 was being developed, someone suggested that it would be nice if we could get the IBM plotter to do the isoline maps; consequently, John Lambe, BLM Chief of the Branch of Automatic Data Processing, agreed to write the programs necessary to make machine-produced isoline charts.

FIGURE 3.—Tabulated Output from WEA2.

ALL STATIONS					
DAILY FIRE DANGER			ACTUAL		
STA	PREC	FFM	BI	SI	CL
CIL	0.13	13.0	36	12	2
UNK	0.07	16.0	10	34	3
IAN	0.00	11.0	33	21	2
TAY	T	30.0	31	1	1
BTT	0.11	10.0	22	25	2
GAL	0.02	13.0	12	33	3
HSL	0.06	13.0	27	23	2
KUK	0.12	10.0	7	27	2
TAL	0.28	10.0	31	37	3
UTO	0.02	13.0	15	20	2
CEM	0.03	8.5	24	23	2
EAA	0.17	9.0	33	35	3
FYU	0.17	10.0	22	22	2
SVS	0.15	12.0	41	13	2
CIK	0.08	9.5	51	21	2
BET	0.40	30.0	5	5	1
ANI	0.33	16.0	5	22	2
FWL	0.01	13.0	18	23	2
MCG	0.10	16.0	11	19	2
SLQ	0.15	30.0	76	1	1
BIG	0.15	8.0	42	49	4
FAI	0.05	8.5	34	47	3
ENN	0.21	9.5	36	33	3
ORT	0.13	9.5	18	28	2
TSG	0.00	5.5	40	66	4
SOF	0.00	8.0	38	39	3
AKN	0.06	16.0	22	34	3
KNW	0.26	12.0	11	41	3
SVW	0.07	30.0	6	5	1
ILI			30		
ANC	0.00	9.5	25	44	3
BVD	0.00	12.0	59	21	2
CDV	0.26	15.0	4	8	1
GKN	0.02	7.0	50	69	4
HOM	0.03	30.0	42	1	1
ENA	0.01	15.0	32	18	2
LWG	0.00	15.0	30	10	1
SKL	0.00	15.0	59	14	2
UMM	0.22	11.0	7	44	3
TKA	T	9.5	9	21	2
WLA	0.00	9.5	11	14	2
MXY	0.00	12.0	12	11	1
ENN	0.00	10.0	18	13	2

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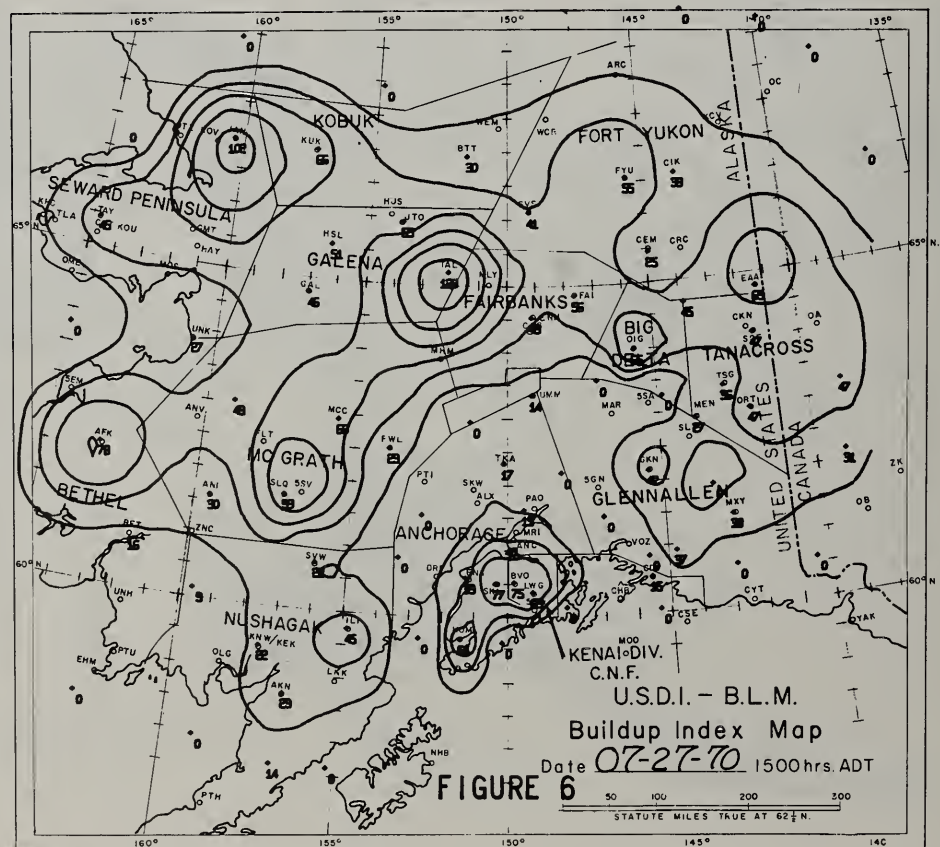
Two additional programs were written, the first, labeled PUNX, reads buildup index values from the disk as computed by WEA2. It also computes BUI values at "dependent data points."

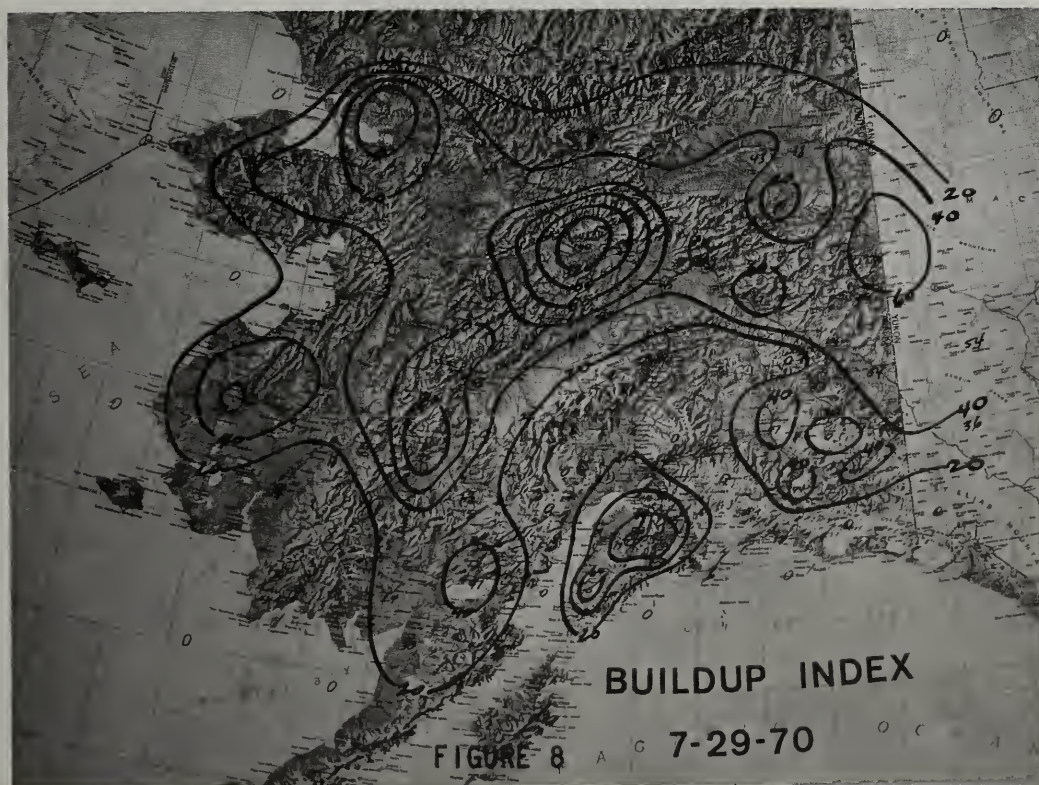
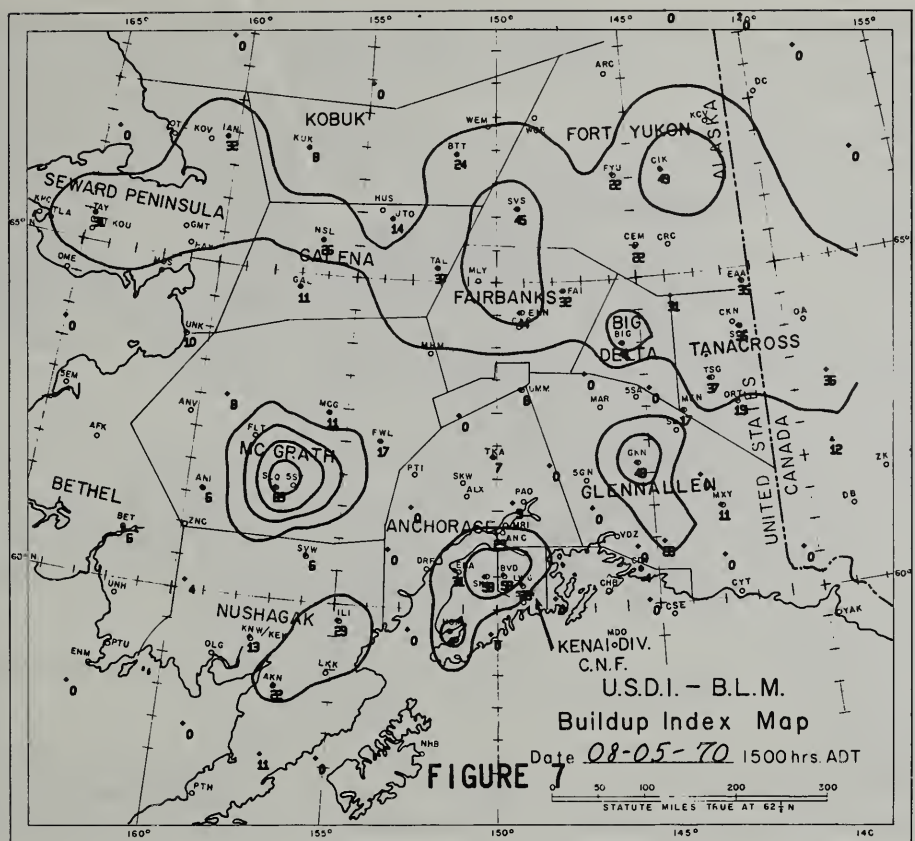
Most of the observation stations in Alaska are along the coast or along the rivers. There are very few stations in the mountains or even in the hills. You will note that Station Z51 (fig. 4) is over a range of low hills called the Killbuck Mountains. These are not much compared with what we normally think of as mountains in Alaska, but there are numerous rounded peaks as high as 4,000 and 5,000 feet, and they cover quite an area. There are no observations from this area. A group of fire-weather and fire-control people got together and hypothesized what the fuel moisture and fire-danger ratings might be in that area, based on experience, past fire history, etc. The group came up with the following formula for Z51 (fig. 5).

Note that Z51 is a function of Z16 and Z33. In fact, Z51 is one-half of the averaged values of Z16 and Z33. Other formulae were derived for other locations.

PUNX also punches cards of buildup index values. These cards and data are required as input to the next program, POSTW.

POSTW inputs the data from PUNX off the punched cards and plots the buildup index on the isoline map. It then calls the contouring package, "NUMERICAL SERVICES TECHNIQUES IBM 1130 CX 11X CONTOUR PACKAGE VERSION 2." The contour package completes the job. Figures 6 and 7 are examples of the completed product.





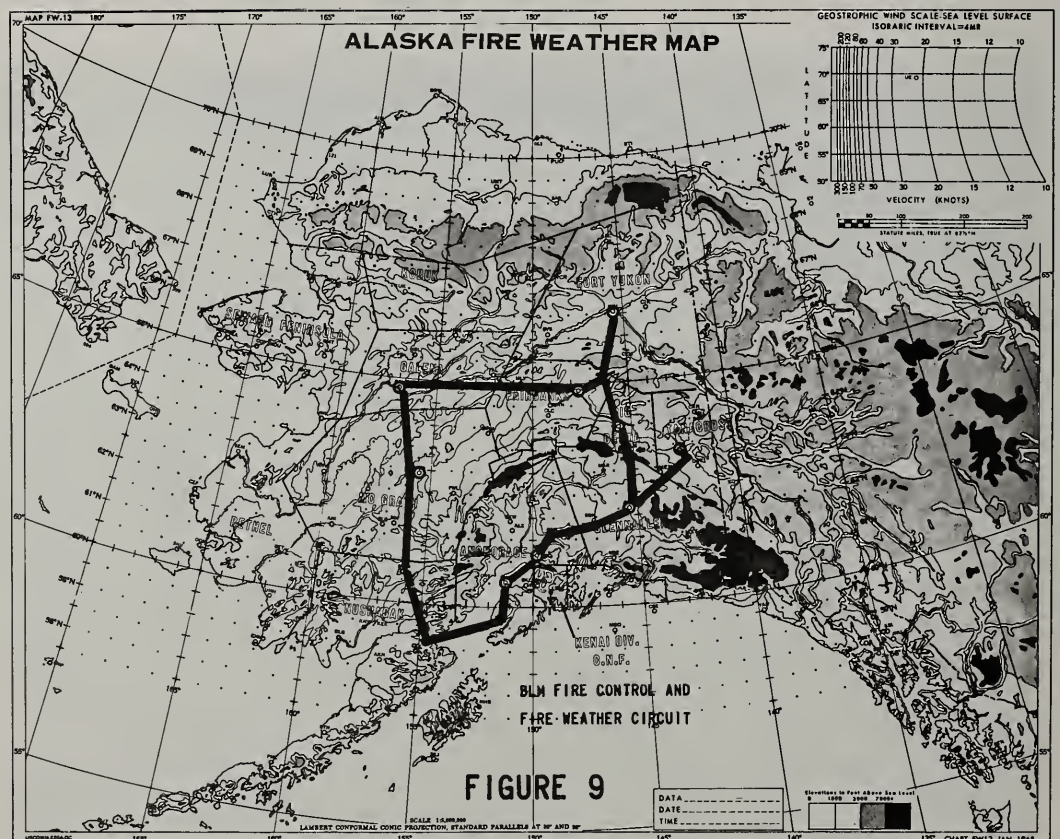
Note on these completed isoline maps that the program has plotted data values of zero over the major mountain ranges and over large bodies of water. This is based on the premise that buildup index values are always zero over snow-covered areas and over large bodies of water. Let us take the computer-produced isolines and transpose them to a map where the topographic features are more evident (fig. 8).

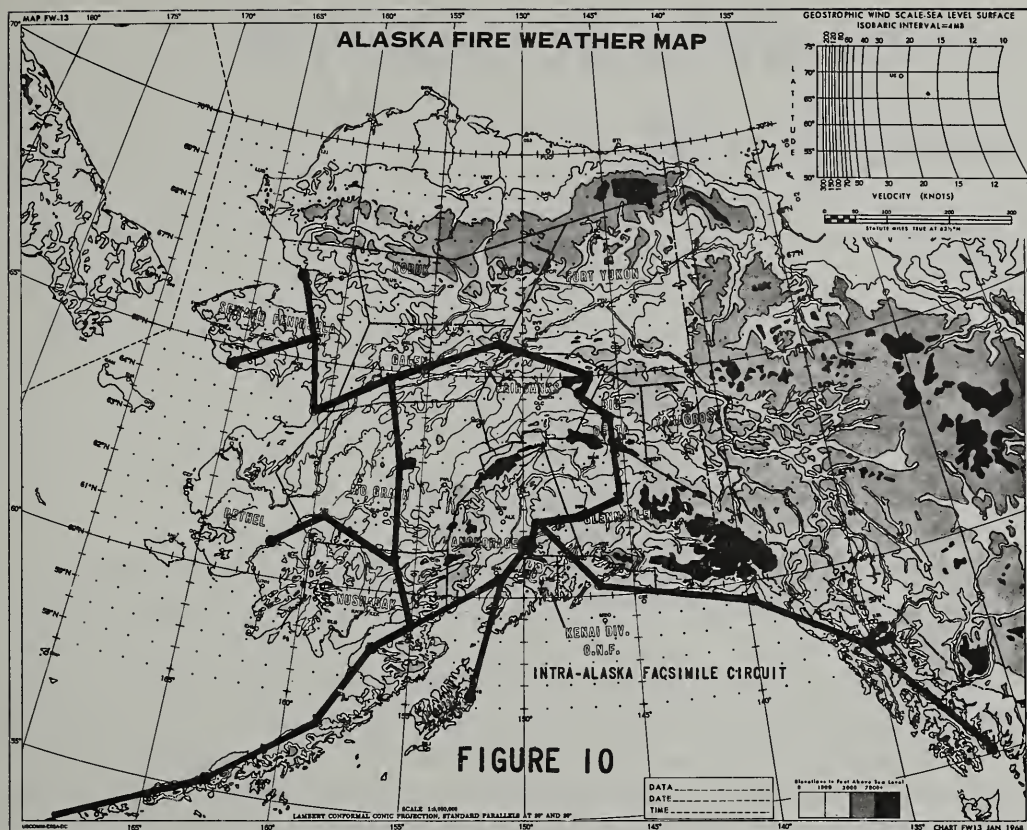
Notice how, with the help of the hypothetical data points and the fixed zero values, the computer takes into account topography, and to a certain extent, climatology, since climatology was subjectively estimated when constructing the formulae for the hypothetical data points.

In many respects, the computerized fire-danger rating system can be improved upon; but even if it were perfect, its value would be greatly reduced if there were no effective method of disseminating the output. The tabulated data are disseminated on a real-time basis by the BLM teletype network for fire control and by Service 0—Federal Aviation Administration aviation circuit. The BLM circuit is shown in figure 9.

Service 0 is a national circuit, and its function, in this case, is to transmit the data to the Boise Interagency Fire Center in Boise, Idaho.

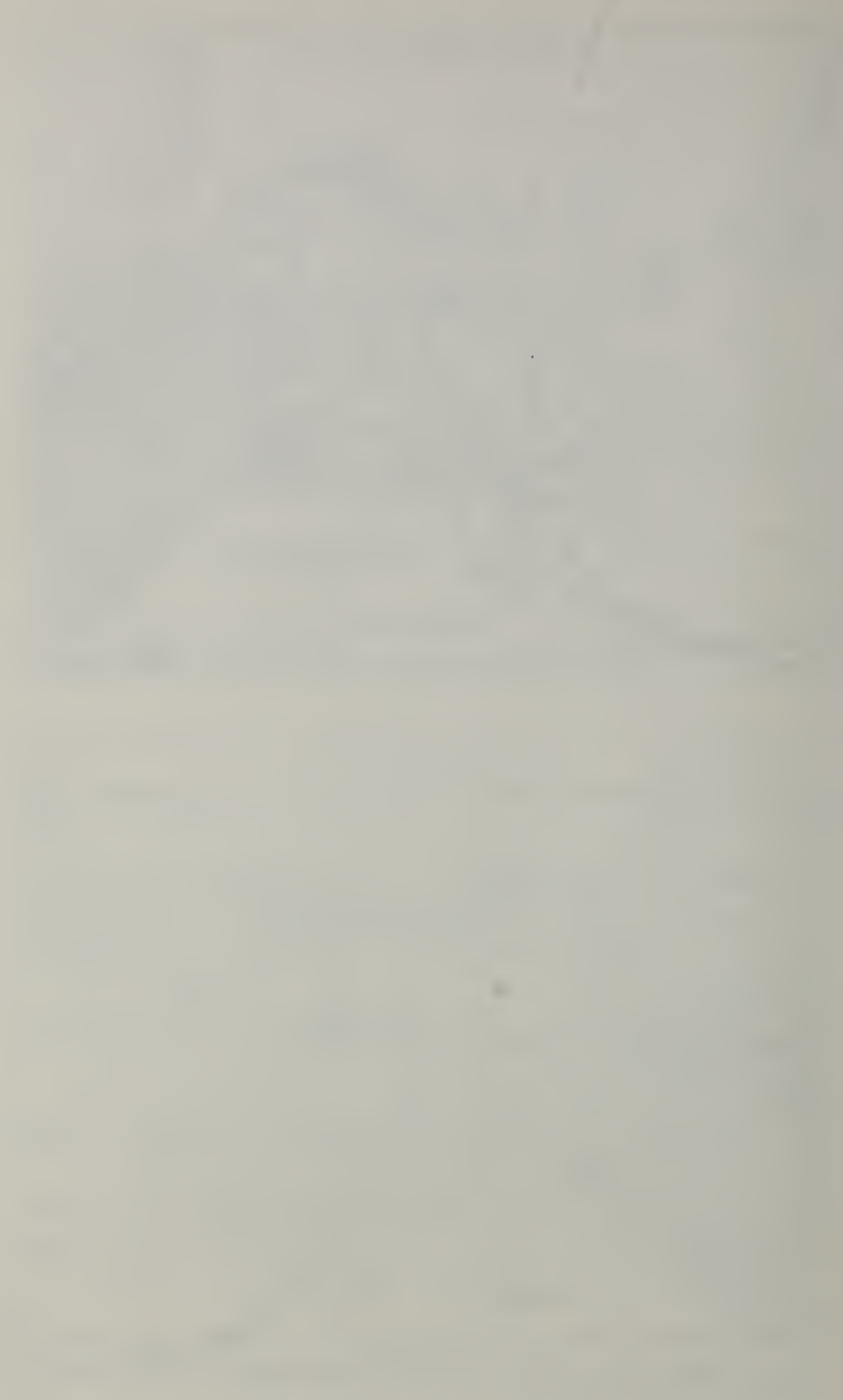
The isoline map is transmitted on Intra-Alaska Facsimile (fig. 10). It is also transmitted by telecopier to Boise, Idaho. And finally, it is transmitted by messenger to the BLM Division of Aircraft in Anchorage.





For system evaluation purposes, the following factors should be considered:

1. **VOLUME.** The system becomes more efficient with added volume since the time to set up and discontinue the run remains the same. The time difference in computations and printout between low and high volume is negligible.
2. **ECONOMY.** At this stage, I believe that no money is saved in man-hours unless recall and correction are involved or if the volume increases.
3. **RELIABILITY.** Near maximum.
4. **RECALL AND CORRECTION CAPABILITY.** Far superior to hand methods.
5. **RECORD STORING.** Excellent, except not as accessible as hand method.
6. **REAL-TIME ASPECTS.** Fair. An experienced individual can produce about as fast as the machine, but the individual cannot produce any significant increase in volume.
7. **IMPROVEMENT POTENTIAL.** Considerable. Overall, I would evaluate the present system as good. In addition, it provides an excellent backup and check of the hand system.



Weather modification— a fire control tool

Abstract

The application of weather modification techniques as a fire control tool was field tested in Alaska during the summers of 1969 and 1970. The 1969 trial was primarily exploratory. Data gathered indicated clouds or cloud-systems exist in interior Alaska which are amenable to current cold cloud modification techniques and could be used in fire control. Based upon these data and results obtained during 1969, a full-scale field trial was designed and conducted during June and July of 1970. Organization of the project, equipment, and facilities—as well as the imposed constraints—are discussed. Results show cloud seeding can be an effective fire control tool when the proper meteorological conditions exist. The potential is great if application can be made under these conditions. However, like any tool, weather modification techniques can only supplement other fire control techniques already in use.

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Resources Management
Bureau of Reclamation
Department of
the Interior
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The summer of 1969 presented the worst fire siege in Alaskan history. The combination of a series of unprecedented dry seasons extending through two summers and the 1968-69 winter had set the stage. An abundance of dry lightning storms in turn had added the key ingredient of ignition. In a description of the situation early in June of that year, the Bureau of Land Management (BLM) said,

Alaska is currently experiencing a most severe fire season, due to extremely dry conditions and occurrence of dry lightning storms. Over 3 million acres have been burned since January 1, 1969. It is considered that an extreme emergency situation exists in Alaska at this time.

Grasping at every means of alleviating the problem, the Department of the Interior surveyed the capabilities of its various agencies and considered with new interest the Bureau of Reclamation and its Project Skywater—a scientific research program of cloud seeding to augment precipitation in water-short areas of the Nation.

The question, "Could cloud seeding be employed in fire control in the existing emergency?" was asked of Dr. Archie M. Kahan, Chief of Project Skywater. His response, conservatively phrased, was that cloud seeding should not be ruled out, that there are some possibilities which hold promise; however, evaluation of results would be most difficult. Following additional discussions, the Bureau of Land Management decided to go ahead with a short trial period during July and requested technical assistance from Dr. Kahan's staff. I was given this assignment.

Officially named Project MOD, the staff consisted of personnel drawn from the Weather Bureau, the Forest Service, the Bureau of Reclamation, South Dakota School of Mines and Technology, and EG&G, Inc. (the seeding contractor), in addition to personnel from BLM. Organization of the MOD Squad, as it came to be known, was headed by Mr. James Richardson, BLM's Chief of Fire Control for Alaska. In addition to support elements, the MOD Squad contained three major groups—the Weather Advisory group (WAG), the Field Evaluation Group (FEG), and the seeding contractor (Appendix 1). Equipment included both high- and low-level observational aircraft, a helicopter for FEG transportation, an infrared-equipped aircraft, and the seeding aircraft. Arrangements were made to use a program from the Project Skywater library for analysis of soundings by the University of Alaska's computer center and to employ U.S. Air Force radar for cloud observation. The field experimental period was 10 days from July 24 through August 2 of 1969.

Seeding was to be conducted with pyrotechnics fired vertically from the aircraft at the level of -10° C. down through the cloud. Each round would release 30 grams of silver iodide. The number of rounds fired would be determined by direct observation from the seeding aircraft.

The objective of the project was to produce precipitation on forest fires in Alaska. To accomplish this, a going fire was designated as the target; a suitable cloud or cloud-system which would move over the target was selected and seeded to produce the maximum precipitation on the target.

Evaluation was to be made by the FEG whose members would be located on the target fire and would accumulate data using belt meteorological kits, time-lapse motion picture cameras, and visual observations. The infrared-equipped aircraft would scan the target prior to and after precipitation. Radar observations of the selected cloud or cloud-system would be made. Visual and photographic observations would be made from all other aircraft.

Fundamental requisites for the operation are, first, a target fire and, second, meteorological conditions which will produce clouds amenable to modification by cold cloud modification techniques.

With the existing fire situation in July 1969, finding a target fire was no problem. Suitable meteorological conditions during the 10-day operational period, however, did present a real problem. During this period, the weather conditions which existed were marginal to unsuitable for cloud seeding.

Operations, all conducted in the Fort Yukon area, appeared to stimulate precipitation on 2 days and rain fell on or near existing fires, producing a detectable suppressive effect. A summary of the operations is shown as Appendix 2.

The conclusions, as stated in my report to BLM, contain the following comments:

In assessing the potential of weather modification techniques for a particular purpose, two factors are of prime importance:

1. Are the clouds/cloud systems suitable for modification?
2. If modified, will the resultant increase in precipitation produce the desired effect?

Based on the results of Project Skywater research programs extrapolated to Alaska and meteorological observations made during Project MOD, clouds/cloud systems which occur in Alaska appear to be suitable for modification by cold cloud techniques.

This conclusion, coupled with information gained from discussions with BLM and Forest Service fire control personnel concerning the amount of precipitation required to produce a beneficial effect, indicate a potential does exist for the employment of weather modification techniques in Alaska for fire suppression, control, and especially fire pre-suppression.

Recommendations included consideration of an extended operational period to begin earlier (before July) and continue for at least 30 days.

Based upon the results of the 1969 program, the BLM decided to carry out a second operation during the summer of 1970. This project, however, was conducted for a 60-day period from June 1 through July 31. An expanded staff and supplemental equipment were employed, and an advanced computer model was run on the University of Alaska's computer to refine the operational phase and provide a more definitive evaluation.

The primary objective was to seed clouds over or near wildfires to induce rain in amounts which would be beneficial to fire control. The primary project area was circular with a 50-mile radius around Galena where the operational equipment and field personnel were based. An extended area of operations, within 200 miles of Galena, was an option, as were similar circular areas of 50- and 200-mile radii with Fort Yukon as the center. Should the Fort Yukon areas be used, Fairbanks was to be the operations base. Overall meteorological support and project direction were from Fairbanks in all cases.

The project staff organization again consisted of three major elements—the weather team, the fire and fuel team, and the contractor (Meteorology Research, Inc.).

Project headquarters was established in Fairbanks where the project leader, two members of the weather team, the contractor project manager, and support personnel were based. Also based in Fairbanks were the high-level observation and control aircraft and an aircraft equipped with infrared cameras.

At Galena were the fire and fuel team consisting of the team leader, seven observers, a low-level observation aircraft and pilot, two helicopters and pilots, one member of the weather team, the contractor field operations group (consisting of the field manager, rawinsonde, and operator), the radar and operator, and the seeding aircraft and pilot. The project organization is shown as Appendix 3.

In order to determine areas suitable for cloud seeding, daily analysis of weather information, both surface and aloft, was required. Upper air soundings from appropriate available Alaskan stations were needed, and additional upper air characteristics in the vicinity of Galena were necessary for more detailed analysis. A numerical computer model utilizing this upper air information and a computer facility were additional tools used to assist in the determination of conditions suitable for cloud seeding.

To properly evaluate the effectiveness of cloud seeding for retarding fire spread, ground observations and measurement of precipitation produced were needed, and information on the reaction of fine fuels to the precipitation was desirable. The use of radar for tracking seeded clouds and aircraft visual observations of seeding effects, precipitation tracks, and effects on fires were included in the operation.

In addition to the excellent logistics and technical assistance from the BLM Fairbanks District Office and Fairbanks District Operations, the support from the Weather Bureau's Fire Weather Office, the Forest Service's Forestry Sciences Laboratory, and the University of Alaska computer center provided significant and necessary inputs.

The FAA flight service station at Galena provided teletype weather information from Service "A" and "C." It was used by the project radar meteorologist for weather analysis and subsequent project briefing for the field team leader and flightcrews on a daily basis.

The scientific basis for seeding cumulus clouds to produce increased rainfall has evolved considerably since the first experiments in 1947. It was thought that the principal role of artificial ice nuclei in cumuli was to trigger the Bergeron rain mechanism. As seeding experiments became more common, it was found that the dominant effect of the artificially produced ice crystals in cumuli was not to initiate the Bergeron mechanism but rather to increase the vertical extent of the clouds. The heat released by freezing the supercooled water in cumuli is often enough to double a cloud's buoyancy and trigger vertical growth in several thousand feet. This increased vertical growth will generally increase the cloud's precipitation by intensifying the circulation in the cloud, thus causing the cloud to process more water vapor

into liquid water. Until recently, very little mention was made of increasing the horizontal dimensions of the cloud.

As a result of experiments carried out in Flagstaff, Arizona, under Bureau of Reclamation sponsorship and by National Oceanic and Atmospheric Administration (NOAA) in the Caribbean, it is now clear that under some conditions the horizontal growth of cumuli is more important than the vertical growth. If, through judicious seeding, one can double the horizontal dimensions of the cloud, the precipitation can be increased by a factor of 8 to 10. A doubling of precipitation was considered maximum when only vertical growth was hypothesized to occur due to seeding.

It is clear from these experiments and others that horizontal growth resulting from seeding does not occur as rapidly as is the case with vertical growth. The first phase is a pronounced vertical growth. If the seeding is continued, the heat released within the cloud by the freezing of supercooled water serves to organize the cloud updrafts into one coherent core, through which a new surge of moisture is drawn. It is with this new moisture surge that the horizontal dimension of the cloud is increased.

With these concepts in mind, the seeding procedure should involve techniques to induce vertical growth first, and then horizontal growth. There are two techniques that have been successfully employed to increase the vertical dimension of cumulus clouds through airborne seeding. The first technique, employed in the Caribbean and at Flagstaff, uses vertical-fall silver iodide pyrotechnics. These devices are fired into the top of a rising cloud turret as it passes the -10° C. level. The technique has the advantage of making certain that the seeding material enters the supercooled region of the cloud and that it arrives there at the correct time. This technique is best used on relatively small clouds that cannot be made to grow horizontally and on somewhat larger clouds to spur the vertical growth phase mentioned earlier.

The second technique of airborne seeding has been successfully used in Flagstaff, Arizona, and elsewhere. It involves below-cloud seeding with either an acetone-silver iodide mixture or silver iodide pyrotechnics burned from the wing of an airplane. This technique has the disadvantage of relying on the cloud updrafts to advect the seeding material into the supercooled region of the cloud. If the updrafts are weak or intermittent, the technique cannot work, as the material will not reach the supercooled region of the cloud at the right time in the cloud's lifetime.

The below-cloud technique has some distinct advantages, however, when the cloud has a strong, persistent updraft. Under these conditions, the material is advected into the right parts of the cloud, over an extended period of time, and over the whole width of the updraft core. This time and space spread of the seeding material fosters the horizontal as well as vertical growth of the cloud.

The seeding aircraft was equipped to employ both techniques and used both methods during seeding. The choice of which technique to use was

based upon advance numerical model calculations and visual observations of the response of the clouds during the operations.

A version of the Weinstein-Davis numerical cloud model was used with the University of Alaska IBM/360-40 computer. This model combines the accuracy of detailed calculations, where the cloud mechanisms are well understood, with the speed of parameterization where the phenomena are complex, and was produced for use as a field operations tool.

The computer program is divided into two main sections—interpolation and model computation. The interpolation section takes a standard radiosonde sounding of pressure, temperature, and relative humidity, at mandatory and significant levels starting from observed or calculated cloud base. This sounding is expanded to equally spaced vertical intervals. In this case, 200-meter intervals were applied. The computation section of the model included the thermodynamics, cloud physics, dynamics, and auxiliary calculations.

A full range of cloud sizes from 0.5-kilometer radius to 5.0-kilometer radius, each with ice nucleation temperatures of -8°C . and -25°C ., was run through the model in order to define the size of cloud, if any, most susceptible to seeding. The increased height of cloud top and increased amount and duration of precipitation were then used as a basis for comparison with the analysis of other weather information to determine the probability of effecting cloud seeding within the operating areas. In general, an increase in cloud top height of about 3,000 feet and an indication of 0.1 inch or more of rain on the ground were the criteria used to determine suitability for seeding.

Mathematical modeling of cloud processes was performed daily using the Galena upper air sounding. When appropriate, based on analysis of current weather patterns, one or more other soundings in or near the operating area were also used.

In order to determine the probability of suitable cloud seeding weather within the operating area on both a current and a forecast basis, certain data were considered to be most desirable. Of particular importance was the need for daily upper air sounding data from stations in or near the area, which would be representative of the air mass characteristics within the area. Upper air soundings were available at the Fairbanks fire weather office on teletype service "C" from six reporting stations surrounding the area. A project rawinsonde unit was installed at Galena to fill the gap in the regular station network, and the sounding information was transmitted to the project Fairbanks office via BLM teletype. Synoptic surface weather observations and 500-millibar data were also available at Fairbanks, and daily surface and 500-millibar charts were plotted and analyzed each morning. At Galena, an additional streamline (windflow) analysis over Alaska was made using the 12,000-foot winds. Early observations of cloud depth and movement in the project area indicated that this level of windflow could be used for an initial estimate of cloud movement for operational preflight planning and briefing. Facsimile weather charts received from the national network and from the

Anchorage Weather Bureau office were also used on a daily basis, primarily as extended forecast tools. Hourly surface observations from Alaskan stations were received in Fairbanks and were particularly useful in forecasting maximum temperatures in the area to determine the likelihood and starting times of convective cloud activity.

The weather radar at Galena was used primarily as an operational tool to track and obtain the speed and direction of movement of cumuliform clouds. Additional information on location and severity of storms which could cause lightning strikes was obtained and relayed to the Galena fire control office to aid in establishing patrol areas.

The operational procedures and routine established at the beginning of the project were varied only slightly throughout the 2-month operating period. The responsibilities and functions of all personnel were established to provide an operational capability 7 days a week. The basis for each day's activities was then the collection and evaluation of current and expected weather and fire conditions, to determine if seeding operations would be conducted. For the purposes of this project, an "operational day" was defined as one in which operating area weather conditions existed, or were forecast, and were conducive to cloud seeding to induce precipitation; and one or more fires were going in this same area. It was emphasized by BLM that seeding efforts "must be directed toward providing timely precipitation at critical points either directly on a fire, or immediately ahead of the fire line, and in sufficient quantities to effectively aid in suppressing the fire. The mere production of rainfall without regard to location is not desired." The criterion for defining "sufficient quantities" was established as 0.1 inch or more of precipitation on the ground as forecast from available data, using the computer model output as a guide.

An outline of the typical daily routine is as follows:

Project Schedule

- 0400- Weather data received at the Fairbanks weather office were plotted
0800 and analyzed by the weather team to provide current information on weather conditions throughout Alaska, with primary concern for the assigned operating areas. Prognostic facsimile weather charts were collected and reviewed. At Galena, the rawinsonde team took the upper air sounding and transmitted the data via teletype to Fairbanks.
- 0700 The upper air sounding from Galena, received on the BLM teletype circuit, was plotted and analyzed for stability and moisture characteristics. This sounding and one or more others from representative stations near the operating area were transcribed into IBM punchcard format and delivered to the University of Alaska computer center about 0730. The cloud model program was run on the University computer and the generated output returned to project headquarters. At Galena, the radar meteorologist plotted and analyzed the soundings and prepared the 12,000-foot-level streamline analysis. Aircraft

were preflighted and equipment readied for the day's operation.

0800 Fire condition reports were discussed with district fire control personnel.

Project headquarters personnel were briefed on weather and fire conditions for the current day. Forecasts were presented for the ensuing 3 days. A decision was made at this time on the day's operation and a message (see example below) transmitted to the Galena base giving a "weather summary," and, if appropriate, the "seeding data." Weather and operational briefings were also conducted daily at Galena by the radar meteorologist and the fire and fuel team leader.

WOO-GAL Weather Summary

SURFACE—E-W TROF OVERLIES CENTRAL ALASKA BETWEEN THE BROOKS AND ALASKA RANGES. RIDGE ALONG EAST GULF COAST NORTHWESTWARD TO COOK INLET.

500MB—LOW CENTERED OVER BRISTOL BAY. LIGHT TO MODERATE SOUTHEAST TO EAST FLOW OVER THE STATE.

STABILITY—CONDITIONALLY UNSTABLE.

FORECAST TODAY—MOSTLY CLEAR BECOMING PARTLY CLOUDY AFTERNOON WITH TCU, RW, AND TRW.

TOMORROW—INCREASING CLOUDINESS, SCATTERED RW.

OPERATIONS—GO.

SEEDING DATA

TARGETS—FIRST HUNGER 9633, SECOND OCTOPUS 9618, THIRD DAKLIA 9601.

CLOUD BASE—4000 FT.

-10C LEVEL—13000 FT.

MIN CLOUD DIAMETER—2½ MILES.

UNTREATED CLOUD HEIGHT—14500 FT.

TREATED HEIGHT INCREASE—5500 FT.

RAIN AMOUNT TREATED—0.12 INCHES.

RAIN DURATION TREATED—16 MINS.

CONVECTION WILL BE INITIATED AT 1100 WITH SURFACE TEMP OF 63F,

START SEEDING 1200

WOO-FAI WJD 7/15/70 0915

R DWH WOO GAL

- 0900- If weather and fire conditions were suitable for a seeding operation
1000 and an operational day declared, the Fairbanks-based high-level aircraft proceeded to Galena with the project leader, weather team leader, contractor project manager, and photographer. When time permitted, an operational briefing was conducted at Galena for all participating personnel.
- 1100- On operational days, an additional upper air sounding was taken at
1500 Galena at the time operations were being conducted and radar tracking and assessment were in progress.
- 1500- On completion of flight operations, a debriefing was held at Galena
2000 for all participating personnel. The project headquarters staff returned to Fairbanks and reviewed the forecast weather and fire conditions for the following day.

Operations

During the month of June 1970, there were 12 days in which the weather was suitable for cloud seeding in the Galena area. On 7 of these days, there were no active fires in the area (Appendix 4). Of the 5 days in June on which fires occurred in this area, operations were conducted on 4 of these days—June 11, 14, 16, and 30. On June 29, the area northeast of Galena in the vicinity of the fires did not have suitable seeding weather.

During July 1970, fires became numerous in the area north and east of Galena early in the month and a few were still in mopup on July 31 (Appendix 4). Weather in this area was operationally suitable on only 4 days during this period, and seeding operations were conducted on these days. Two additional operations were conducted under marginal weather conditions for a total of six during the month.

A summary of the weather during June and July is shown in Appendix 5.

On July 20, the seeding aircraft and crew, plus one ground crew team and helicopter, were moved to Fairbanks and the operating area extended, operations then to be conducted within 200 miles of Galena and the area from the north slope of the Alaska Range to the south slope of the Brooks Range and east to the Canadian border. During the last 10 days of July, there was only 1 suitable seeding day in this extended area, and there were no fires in the area of the weather.

An operations summary covering the pertinent information on the 11 operational days flown is shown as Appendix 6.

The best results in terms of precipitation on fires were observed on June 11 and July 4.

On June 11, seeding weather was favorable in the Ganes Fire area. A cloud about 8 miles upwind of the fire was seeded with two vertical-fall, silver iodide pyrotechnics followed by one slow-burning flare. Cloud growth was observed from the high-level aircraft with the cloud top going from 12,000 feet to 20,000 feet within 10 minutes of seeding. This compared favorably with the computer model prediction of a 7,000-foot height increase due to seeding. The seeded cloud was observed to move over the fire with rain estimated by the fire boss to be about 0.25 inch on the fire. The morning computer prediction was 0.1 inch or more. There appeared to be no other suitable clouds in the fire area at the conclusion of the above operation.

On July 4, approximately 96 fires were burning in the Galena area. The high-level aircraft flew a reconnaissance mission in the vicinity of the Daklia fire and when suitable seeding conditions were observed to be developing, the seeding and observation aircraft were called out. Three clouds were seeded upwind of this fire, and the rain produced appeared to cross the north end of the fireline, knocking down the fire in that area. The morning computer prediction for the Galena area indicated cloud height increases of 10,000 feet and 0.25 inch of precipitation. Observed growth was estimated at 8,000 feet. The afternoon Galena sounding and computer analysis, taken during seeding operations, predicted cloud growth of 7,000 feet and 0.25 inch of rain with a 2-mile-diameter cloud. Enroute back to Galena from this fire area, the ground control aircraft and seeding aircraft discovered a new fire of about 10 acres which was later designated Star Fire No. 9615. Four clouds upwind of the fire were seeded and produced rain on the fire. This fire went from a fast-burning condition with flames and considerable smoke to a smoldering condition.

On four of the other operations (June 16, July 3, July 7, and July 15), results appeared to be only marginal. In each situation, the rain from the seeded clouds either could not be verified as falling on the fire or was observed to fall some distance away. On 3 of these days (June 16, July 3, and July 15), the morning computer prediction indicated growth of about 5,000 feet with 0.1 inch or more of rain. However, by the time of the afternoon sounding, the computer run predicted little effect from seeding, verifying the observed weather during the operations. On the other day, July 7, the Galena sounding indicated no effect from seeding, although the orographic effect in the northern operating area did in fact set off some activity which allowed a seeding opportunity.

On June 14, the seeding operation in the Rennie Fire area was undertaken even though clouds in the vicinity of the fire were small. This seeding produced no effect on the clouds treated and no rain occurred.

On 3 other operational days (June 30, July 2, and July 5), the aircraft were launched for fire areas, but seedable clouds were at distances of 10 miles or more from the fires and not moving in directions to affect the area near the fire. The computer prediction on July 5 indicated no seeding effect, and aircraft were launched on request from fire control. On July 30 the

computer run in the morning was favorable, but afternoon weather in the fire area had changed to dry, also indicated by the afternoon computer output. On July 2, the morning Galena sounding and computer run showed some increase from seeding, but suitable clouds in the fire areas were 10 to 15 miles distant.

Summary

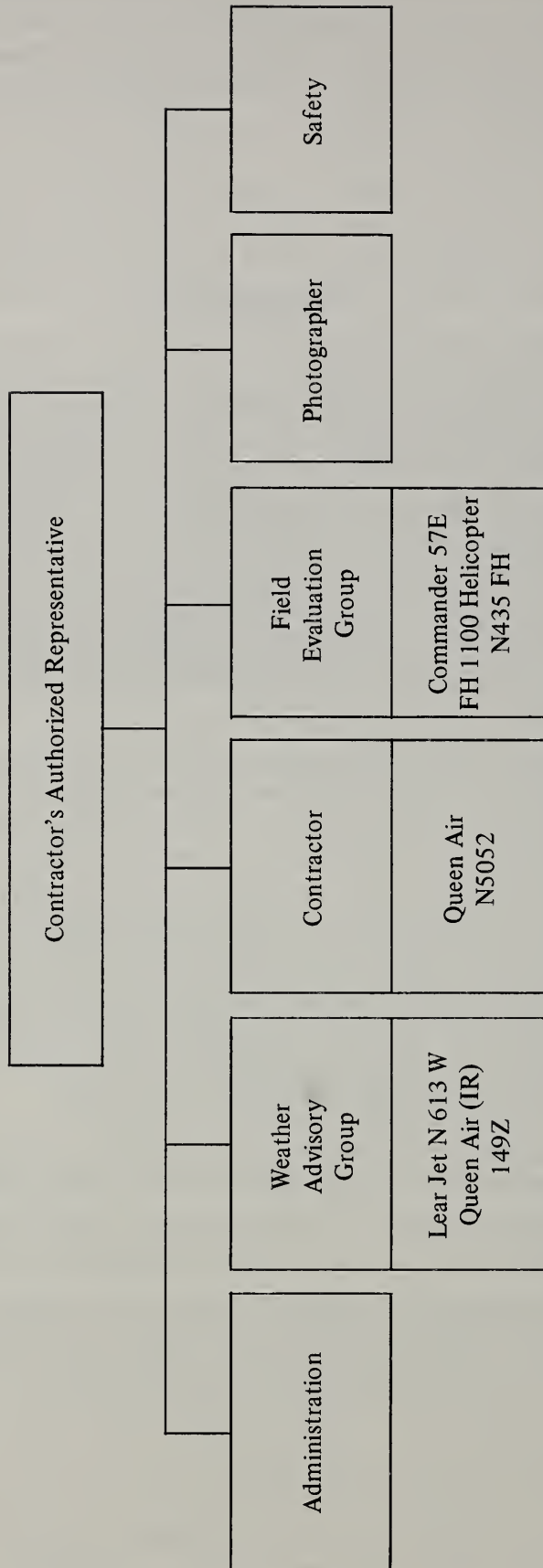
The original plan of operation called for radar coverage and location of the fire and fuel team on target fires for which seeding operations were to be conducted. These procedures were based upon operations within the primary operations area of about 7,500 square miles in a circular area of 50-statute-mile radius around Galena. Unfortunately, no fires which could be acted upon in this manner occurred within this primary operations area, and the data which would have been obtained from the radar and the fire and fuel team were not realized. In their absence, subjective observations became the only basis for evaluating the effectiveness of cloud seeding as a fire control tool.

As was stated earlier, the conduct of a cloud seeding operation for fire suppression depends upon two basic factors: the existence of a fire and weather conditions in the immediate fire area which will produce cloud formations suitable for modification. A review of these two factors during June and July reveals a total of 16 days in an area of 200 miles radius around Galena during which weather conditions were suitable for modification operations. Of these days of potential operation, on 9 there were no target fires available, thus eliminating approximately half of possible test days. On approximately half of those days when both target fires and suitable weather existed, suitable clouds did not exist in the immediate vicinity of the target fire(s), thus further reducing the number of test cases.

Based on subjective observations, beneficial fire suppression resulted from cloud modification on 2 separate days on three separate fires.

With the limited number of test cases, a firm conclusion as to the value of weather modification operations in fire suppression cannot be made. In my opinion, when the proper conditions exist, cloud seeding can be an effective fire control tool. However, like any tool, these techniques can only supplement other fire control techniques already in use. The potential is great if the application can be made under the proper conditions.

Appendix 1
PROJECT MOD ORGANIZATION – JULY 25, 1969



PROJECT MOD SUMMARY REPORT

Day no.	Date 1969	Go or no go	Target	Overall weather outlook	No. pyro-technics fired	Cloud seedability*	Effect on target**	Remarks
1	7-24	No Go		Low stratus, light rain				
2	7-25	No Go		Small scattered cumulus 2,000 feet thick				Lear Jet reconnaissance showed general cloud cover except broken in Bettles area. Many smokes on 9534 and 9406.
3	7-26	Go	Two segments of western perimeter of 9406, 10 miles east of Fort Yukon.	Cumulus with broken cloud cover	14	2	Light rain on part of north target	Code 3 rain east of target on east part of 9406. Rain also on 9539.
4	7-27	No Go		Stratiform with light rain				Mission called off due to low ceilings and icing.
5	7-28	Go	Targets on north side 9406 along Porcupine River, 25 miles NE. of Fort Yukon.	Cumulus embedded in layer clouds, light showers in area	25	2	Light rain on target	Difficult to distinguish seeding effect from local showers.
6	7-29	No Go		General stratiform clouds				Lear Jet patrol observed small cumuliform clouds in Bettles area in late afternoon.
7	7-30	Go	Fort Yukon, Chandalar, Stevens Village area patrolled, none selected.	Flat cumulus 2,000 feet thick		0		Flew reconnaissance of fires 9406, 9578, 9544. No seedable clouds.
8	7-31	Go	Fires on north side 9406 along Porcupine River from Fort Yukon to Shuman House.	Flat cumulus 4,000 feet thick	22	1	0	Clouds dissipated.
9	8-1	Go	Fire 9544 and west end 9406.	Stratified layers with numerous breaks	42	1	0	No rain observed near target.
10	8-2	No Go	Stratified layers with light rain.					

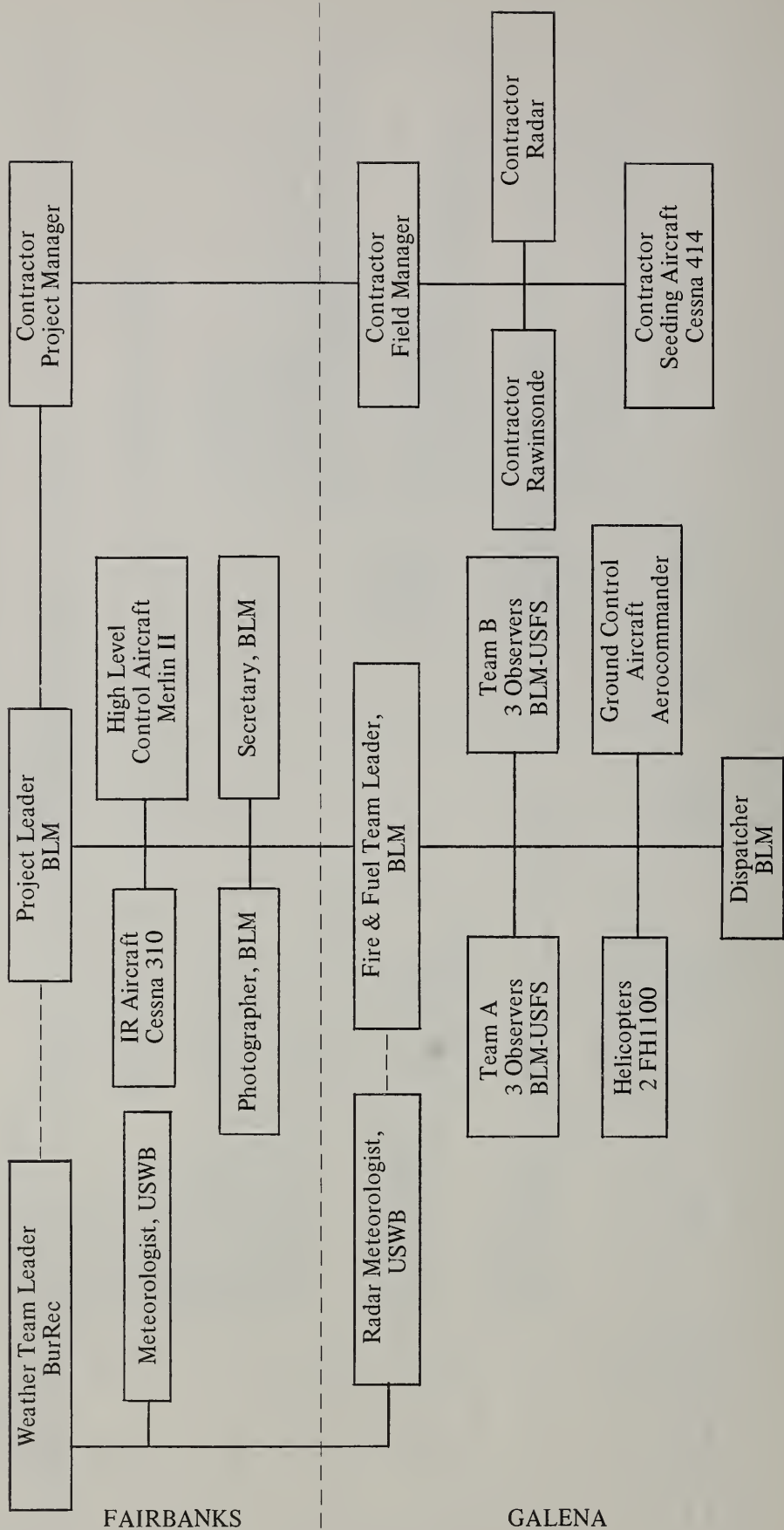
*Cloud seedability rating scale (estimated):

No.	Growth potential	Top increase after seeding
0	None	0
1	Very low	0
2	Low	2,000 feet +
3	Moderate	5,000 feet +
4	Good	10,000 feet +

**Rain intensity code (pilot's view):

0	None
1	Virga
2	Light—rain reaching ground; can easily see through
3	Moderate—see through with difficulty
4	Heavy—cannot see through

Appendix 3
BUREAU OF LAND MANAGEMENT 1970 ALASKA CLOUD SEEDING PROJECT ORGANIZATION



Appendix 4
Weather and Fires
Galena Project Area
June 1970

Date	Seeding Weather	Fires
6-1-70	Not suitable	None
6-2-70	Not suitable	None
6-3-70	Not suitable	None
6-4-70	Not suitable	None
6-5-70	Not suitable	None
6-6-70	Not suitable	None
6-7-70	Not suitable	None
6-8-70	Not suitable	None
6-9-70	Not suitable	None
6-10-70	Operational--Galena	None
6-11-70	Operational--Galena	McGrath (Ganes-9215)
6-12-70	Operational--Galena	None
6-13-70	Not suitable	None
6-14-70	Operational--Galena	McGrath (Rennie-9221)
6-15-70	Not suitable	None
6-16-70	Operational--Galena east	Galena (Roundabout-9533)
6-17-70	Not suitable	None
6-18-70	Not suitable	None
6-19-70	Not suitable	None
6-20-70	Not suitable	None
6-21-70	Operational--Galena (high terrain)	None
6-22-70	Operational--Galena (high terrain)	None
6-23-70	Operational--McGrath	None
6-24-70	Operational--McGrath	None
6-25-70	Operational--McGrath	None
6-26-70	Not suitable	None
6-27-70	Not suitable	None
6-28-70	Not suitable	None
6-29-70	Operational--McGrath Not suitable--Galena east	Galena (Hog-9571, Hot Springs-9569)
6-30-70	Operational--Galena east	Galena (Hog-9571)

Appendix 4 (Continued)

Weather and Fires
Galena Project Area

July 1970

Date	Seeding Weather	Fires
7-1-70	Not suitable	None
7-2-70	Operational—Galena East	Several (approximately 40)
7-3-70	Operational—Galena	Many (approximately 100)
7-4-70	Operational—Galena	Many (approximately 70)
7-5-70	Not suitable	Many (approximately 50)
7-6-70	Not suitable	Many (approximately 50)
7-7-70	Not suitable	Many (approximately 50)
7-8-70	Not suitable	Many (approximately 50)
7-9-70	Not suitable	Several (approximately 15)
7-10-70	Not suitable	Several (approximately 15)
7-11-70	Not suitable	Few (mopup) (approximately 10 or less)
7-12-70	Not suitable	Few (mopup) (approximately 10 or less)
7-13-70	Not suitable	Few (mopup) (approximately 10 or less)
7-14-70	Not suitable	Few (mopup) (approximately 10 or less)
7-15-70	Operational—Galena	Few (mopup) (approximately 10 or less)
7-16-70	Not suitable	Few (mopup) (approximately 10 or less)
7-17-70	Not suitable	Few (mopup) (approximately 10 or less)
7-18-70	Not suitable	Few (mopup) (approximately 10 or less)
7-19-70	Not suitable	Few (mopup) (approximately 10 or less)
7-20-70	Not suitable	Few (mopup) (approximately 10 or less)
7-21-70	Not suitable	Few (mopup) (approximately 10 or less)
7-22-70	Not suitable	Few (mopup) (approximately 10 or less)
7-23-70	Not suitable	Few (mopup) (approximately 10 or less)
7-24-70	Not suitable	Few (mopup) (approximately 10 or less)
7-25-70	Not suitable	Few (mopup) (approximately 10 or less)
7-26-70	Not suitable	Few (mopup) (approximately 10 or less)
7-27-70	Not suitable	Few (mopup) (approximately 10 or less)
7-28-70	Not suitable	Few (mopup) (approximately 10 or less)
7-30-70	Not suitable	Few (mopup) (approximately 10 or less)
7-31-70	Not suitable	Few (mopup) (approximately 10 or less)

Appendix 5

Weather Summary — June-July 1970

June

During the first week of June, a 500-millibar (mb) low was located off the eastern Arctic Slope with a strong ridge over eastern Siberia. A dry northerly flow of stable air made cloud seeding impossible. At the end of the first week, a major shift in the upper air windflow began. The 500-millibar trough moved from the Arctic Ocean to the southeastern Bering Sea, where it was centered at the end of the second week in June. In the process of shifting, the air cooled aloft, resulting in a more unstable atmosphere over Alaska. Convective showers began to develop over the interior during the first few days of the second week. By the end of the second week, the upper air low was centered over the southeastern Bering Sea, and a cool, moist low level flow of air from the Bering Sea had stabilized the air over western Alaska. This condition was not favorable for cloud seeding, although it produced considerable cloudiness with some natural rainfall. During the last week of June, a 500-millibar ridge from western Canada built westward into Alaska. This shifted the lower level flow of air to the east and warm air flow into Alaska from Canada at low altitudes. A more unstable atmosphere resulted, and convective showers and thunderstorms occurred, making cloud seeding conditions ideal. During the month, 12 days presented conditions suitable for weather modification within 200 miles of Galena.

July

At the beginning of the month, a ridge extended from western Canada westward into Alaska. Moist unstable air covered the State with considerable shower and thundershower activity in the interior. Conditions favorable for cloud seeding were excellent throughout interior Alaska. During the middle of the first week, a 500-millibar trough began to intensify and deepened southward into the Bering Sea. A south to southwest flow developed over Alaska bringing cool stable air from the Bering Sea into the interior. The resulting weather was cloudy and damp over all but the northeast interior of the State. The stable condition of the atmosphere resulted in poor cloud seeding conditions. Convective shower and thunderstorm activity continued over the northeastern interior, however. By the third week of July, the trough in the Bering Sea moved westward and a ridge from western Canada built westward into Alaska. An easterly circulation overlay all but the Arctic coast, where winds were westerly. The circulation caused drying over the State. Convective shower and thunderstorm activity was confined to the slopes of the Brooks Range because of the presence of warm air at altitudes above 15,000 feet in the southern and central portions of Alaska. The atmosphere became even more stable during the final week of July when the ridge over Alaska weakened, the trough in the Bering Sea shifted eastward, and a southerly flow over the State once again developed. The resulting influx of cool, moist, stable air continued to make cloud seeding unprofitable over the entire State. During the month, only 4 days presented conditions suitable for weather modification within the expanded area north of the Alaska Range and south of the Brooks Range from the Canadian border to the Bering Sea.

Appendix 6

OPERATIONS SUMMARY

Date	Operative area	Computer readout	Fires flown and latitude-longitude	Clouds seeded	No. of Very pistol flares used and type	Results/ remarks
6-10-70	50 mi.—Galena (ground observation)	Marginal—Galena Favorable—McGrath	Simulated fire 230° mag 31 nm Galena	One system (2 cells)	3 1 slowburn (168 gm. AgI)	Rain area spread from 1- to 3-mi. diameter, moved to ENE.
6-11-70	200 mi.—Galena (ground observation— negative)	Favorable—Galena Unfavorable—McGrath	Ganes #9215 (150 acres) 63-02N 156-30W	(1) 8 mi. SW of fire (2) over fire	(1) 2 1 slowburn (108 gm. AgI) (2) 1 slowburn (18 gm. AgI)	Cloud No. 1 moved over fire with moderate rain on fire.
6-14-70	200 mi.—Galena (ground observation)	Favorable—Galena Favorable—McGrath	Rennie #9221 (3 acres) 63-38N 156-59W	One cloud over fire	2 1 slowburn (118 gm. AgI)	Little effect. Clouds too small in fire area.
6-16-70	50 mi.—Galena (no ground observation)	Favorable—Galena (marginal in p.m.)	Roundabout #9533 (40 acres) 65-33N 158-33W	(1) Over fire (2) 7 mi. upwind	(1) 1 (150 gm. AgI) (2) 1 slowburn (18 gm. AgI)	Second cloud grew in diameter and light rain observed on or near fire.
6-30-70	200 mi.—Galena (ground observation)	Favorable—Galena (unfavorable to west)	Hog #9571 (15 acres) 65-56N 155-0 SW	None	None	Nearest seedable cloud 15 miles away.
7-2-70	200 mi.—Galena (no ground observation)	Favorable—Galena Favorable—McGrath	Reindeer #9580 (17 acres) 65-25N 154-35W	None	None	All seedable clouds 10 miles west of No. 9580. None in other areas.
7-2-70	200 mi.—Galena (no ground observation)	Favorable—Galena Favorable—McGrath	Oscars Cabin #9577 (2 acres) 66-39N 152-55W	None	None	No cumulus clouds in area.
			Old Dummy #9576 (20 acres) 66-08N 151-48W	None	None	No cumulus clouds in area.

Appendix 6 (Continued)

OPERATIONS SUMMARY

Date	Operative area	Computer readout	Fires flown and latitude-longitude	Clouds seeded	No. of Very pistol flares used and type	Results/ remarks
7-3-70	50 mi.—Galena (ground observation)	Favorable—Galena in morning Unfavorable—Galena in afternoon Unfavorable—Kotzebue	Nay #9586 (80 acres) 65-26N 155-33W Knob #9593 (0.1 acres) Cottonwood #9594 (0.1 acres) (Additional reconnaissance of two priority areas: Holiday Creek #9596 66-23N 155-36W. Daklia #9601 66-15N 156-18W. No seedable clouds near fires.)	One system (2 cells) 5 mi. SE fire All three essentially one fire	2 slowburn (36 gm. AgI)	Light to moderate rain, but not moving toward fire.
7-4-70	200 mi.—Galena (no ground observation)	Favorable—Galena	Daklia #9601 (125 acres) Star #9615 (10 acres) 65-17N 156-39W	3 clouds NW of fire 4 clouds NW of fire	9 1 slowburn (468 gm. AgI) 5 (250 gm. AgI)	Moderate rain on north end of fire No. 9601 Moderate to heavy rain on fire changed flames to light smoke on No. 9615.
7-5-70	200 mi.—Galena (no ground observation)	Unfavorable—Galena	Alameda #9646 (1,800 acres) 65-06N 161-04W	None	None	Assistance requested at Koyuk Village. No seedable clouds.
7-7-70	200 mi.—Galena (no ground observation)	Unfavorable—Galena Favorable—McGrath	Kitlik River #9579 (35 acres) 67-15N 159-48W	One SW of fire	1 1 slowburn (68 gm. AgI)	Moderate rain to within half a mile of fire before aircraft left scene.
7-15-70	200 mi.—Galena (ground observation)	Favorable—Galena Favorable—Kotzebue (Galena unfavorable in afternoon)	Hunger #9633 (3,000 acres) 66-14N 158-55W Octopus #9618 (1,200 acres) 66-00N 157-25W Daklia #9601 (75 acres) 66-15N 156-18W	One None None	3 (150 gm. AgI) None None	Rain area below cloud spread eastward over fire. Clouds unsuitable. Clouds unsuitable.

Background, practice, and potential of chemicals in controlling wildfires

Abstract

Chemicals play an increasingly important role in fire control operations. Techniques have progressed from applications of borate and bentonite slurries in the 1950's, to the current widespread utilization of long-term retardants—diammonium phosphate, ammonium sulfate, and ammonium pyro (poly) phosphate.

It is anticipated that use of fixed-wing aircraft for retardant employment will expand, supplemented by utilization of ground units and helicopters for point applications; however, in Alaska the limited road net restricts application other than by fixed-wing aircraft. The potential for significant environmental damage from use of chemical fire retardants is considered extremely low.

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Chemicals are playing an ever-increasing role in improving the efficiency of fire control operations. The objectives of this review are:

1. To sketch a perspective from which we can examine chemicals as used today and evaluate their potential for further strengthening our efforts toward controlling wildfires.
2. To analyze tomorrow's potential application vehicles and the potential for complementary retardant tailoring.
3. To pinpoint backup problems and progress toward their solution.
4. To discuss problems specific to the Far North, approaches to their solution and some of the ecological considerations involved.

Today's practice is the result of an evolution of chemicals and aircraft. During the 1920's, attempts were made to apply water to inaccessible fire-lines with World War I aircraft. This was essentially abandoned. Experiments during the 1930's (1) showed that ammonium phosphate solutions had promise for subduing wildfires. The conclusion from this early work with chemicals was that they had value only when water was extremely hard to

come by. These chemicals were in somewhat limited supply and high in price, and the rate of activity was slow.

HISTORY

<u>Delivery Vehicles</u>	<u>Timing</u>	<u>Chemicals</u>
World War I aircraft	1920's	Water
	1930's	Ammonium phosphates
Otters, Beavers, PBY's	1950's	Water
TBM's, B-17's, F7F's		Borate
B-25's, B-26's, PBY's		Bentonite
Same aircraft	1960's	Long-term retardants DAP, MAP, 11/37/0 10/34/0
Trend toward larger aircraft		Thickened phosphates and sulfates
Changed aircraft	1970's	Tailored long-term retardants
Helicopters		
Ground tankers		
Sprayers		
?		

The effort leading to the present state-of-the-art dates back no more than about 20 years. During the 1950's, World War II aircraft began to be used in the Western United States and Alaska to deliver retardant payloads (2), and Beavers and Otters were used to apply water from lakes in Central Canada and North-central United States. The first heavily used retardant was borate, which was discontinued because of its soil sterilizing characteristics. Although borate had some true retardancy (effectiveness after drying), its primary value was in its ability to plaster a thick layer of water on the fuel. It was replaced with nontoxic bentonite clay, which was effective only because of its water-holding and coating ability and was, therefore, classified as a "short-term" retardant.

The efforts entered a maturing and sophisticating process during the 1960's. Essentially, the same aircraft were used, but toward the end of the decade a preference for larger aircraft was detectable. The chemicals changed drastically and assumed the direction they are now taking. True "long-term" retardants came into their own. Ammonium phosphate solutions appeared in Georgia, Florida, and North Carolina. Initially, solutions of the dry salts, diammonium phosphate (DAP) and monoammonium phosphate (MAP), were used. Then, for ease of mixing, liquid fertilizer solutions (11-37-0 and 10-34-0) were substituted since they were readily available there in the relatively (to the West) small quantities used.

When DAP solutions were introduced in California, they were found to be unsuitable. Not enough chemical could be deposited on the fuel surface to be effective against the much more severe fire intensities. Also DAP solutions dropped poorly in windy conditions at the altitudes required for

safety in the more rugged terrain. Furthermore, the question of safety from corrosion damage to aircraft was faced squarely. These problems were dealt with by adding thickening agents and corrosion inhibitors. Performance of DAP and ammonium sulfate-based materials was improved to the extent that they totally replaced the earlier materials by 1965.

A. How Do Wildfire Retardants Work?

As now used, chemical fire retardants are a mixture of materials to make them perform in the desired manner. An ammonium salt of sulfuric, phosphoric, or pyrophosphoric acid shifts pyrolysis in the preheating stage towards reactions which convert cellulose (fuel) to carbon and water—absorbing heat and removing fuel. Additives are used to improve visibility and consistency (viscosity), minimize corrosive damage to susceptible materials which retardants contact, and, where needed, improve stability and flow. The major functional components are worthy of review both to point out what can be expected of presently available materials and to suggest possible modifications (in physical or chemical properties). These could be designed into retardants to improve their performance in particular applications.

FUNCTIONAL COMPONENTS

- Retardant salt
- Thickeners
- Corrosion inhibitors
- Color
- Stabilizer
- Flow conditioner

1. The retardants (salts) themselves.

The commonly used retardant salts are diammonium phosphate (DAP), ammonium sulfate, and ammonium pyro(poly)phosphate. Monoammonium phosphate (MAP) has and can be used, but current economics rule it out. The first two are available in dry form and are rapidly dissolved (not slurried as common usage suggests) at the time of use. The third is used mostly from the liquid fertilizer (10-34-0 or 11-37-0) form although a dry relative (12-61-0) is available.

On a weight/effectiveness basis, the phosphates are reported to be effective in direct proportion to their phosphorus or phosphoric anhydride (P_2O_5) content, and ammonium sulfate to be about half as effective as DAP (3). Since the sulfuric anhydride (SO_3) content of ammonium sulfate is identical to the P_2O_5 content of DAP, we conclude that a pound of P_2O_5 equals 2 pounds of SO_3 when uniformly applied to the fuel. The second number in the liquid fertilizer designations refers to P_2O_5 content, and a fertilizer description for DAP is 21-53.5-0.

RETARDANT SALTS

Salt	Pounds to Equal Retardancy of 1 Pound DAP
DAP	1
Ammonium sulfate	2
11/37/0	1.6
Borate	5.0
10/34/0	1.7
12/61/0	0.9

Both laboratory results and field practice support the above within our ability to measure or compare. The Macon Fire Laboratory of the U.S. Forest Service reported the first four rankings of effectiveness. Effectiveness of 10-34-0 and 12-61-0 were calculated from the ratios of their P_2O_5 content to that of DAP. The best field use comparisons are available for DAP vs. ammonium sulfate. The commercial products PHOS-CHEK® 202, fire chemical, and Firetrol* 100, fire chemical, at recommended use levels have been considered equivalent for many years on the basis of field evaluations. To gain equivalence with sulfate, the Firetrol 100 uses a combination of 50 percent higher salt concentration than that of DAP in the PHOS-CHEK and employs a clay thickener to plaster a thicker layer on the surface of the fuel. This equivalence illustrates three different approaches toward obtaining the desired performance in a complete retardant—retardant concentration, layer thickness on the fuel, and specific effectiveness of the salt.

2. Consistency (viscosity).

Viscosity control is obtained through the addition of gum or clay thickeners. These are added to control the thickness of the layer which clings to the fuel and to modify the drop pattern as the retardant leaves the aircraft. Clay thickeners have the property of depositing a thicker layer than gums at the same apparent viscosity, because they don't flow at all under gravity when on the fuel as a layer. They only exhibit their viscosity when moving or forced.

Gum thickeners flow more slowly as viscosity increases, but flow tends to continue as long as there is any driving force (such as gravity), as with honey. For this reason, the properties of clay-thickened materials are not directly comparable with those thickened with gum on a number-for-number basis. In fact, the same numbers obtained with the same type of standardized viscometer can have different meanings when different gums are

*Registered trademark of Arizona Agrochemical Company.

involved. For example, if one measures time of passage through a Marsh Funnel for a CMC (carboxymethylcellulose) thickened retardant, which indicates 1,000 cps (centapoise) on a Brookfield viscometer, he will observe a time of 90 seconds. A Guar-thickened retardant indicating 1,000 cps on a Brookfield will show 30 seconds on the Marsh Funnel. This indicates identical resistance to flow at the higher shear rate of the Brookfield, but a marked difference when pulled only by gravity.

EFFECT OF THICKENER TYPE ON APPARENT VISCOSITY

Thickener Type	Brookfield CPS	Marsh Funnel Seconds
CMC	1000	90
Guar	1000	30
Clay	1000	27

Discrepancies such as these do not imply that either of the instruments or either of the retardants are good or bad, but they illustrate the possibility of comparing apples with oranges in selecting numbers for specifications or evaluations. Empirical relationships between air drop and on-the-fire behavior and numbers obtained on either of the instruments, or indeed other instruments, are quite valid for defining a desired performance for retardants utilizing a specific thickener—the numbers just can't cross over. In fact, we may one day be independently controlling various properties of flow to optimize retardants of greater sophistication than those we use today, *if* it is shown that these properties can independently benefit performance on the fireline.

Ideas on how viscosity control can be used to improve the effectiveness of retardants applied in different ways are given below to illustrate their use.

From fixed-wing aircraft, a fairly tight drop pattern can penetrate wind and reach the target from higher altitude than can a diffuse spray. This can be achieved through increasing viscosity, reducing speed, or modifying the discharge characteristics of the drop tank (an all too little understood area). For the near term, we are going to use the hardware we have, and both tank discharge and minimum speed are characteristic of the hardware and not usually within our control. Viscosity, however, can be modified rather easily, if a better definition of what is wanted becomes available. A ceiling is imposed on viscosity increases by the real possibility of making a retardant so thick that it will not spread on the surface of the fuel to provide complete coverage at an economical application rate. Likewise, wind drift and layer thickness requirements impose a floor.

EFFECT OF THICKENERS

<u>Thinness</u>	<u>Thickness</u>
Wind drift	Penetrate wind
High drops disperse	High OK
Larger area	Slow flow
Easier flow	Thick layer
Shadowing	Wrap around
Thin layer	Smaller pattern
	Greater percent of drop on target

As currently used, thickened, long-term retardants have controlled viscosities to provide what appears to be a satisfactory compromise for the severe problems of southern California. Further attention is being given to this question as it may apply to the Far North. It appears that a somewhat thinner material carrying more retardant salt in a gallon might provide greater efficiency (treated area per gallon) in the North where high level drops are seldom necessary and fire intensities are not so great as to require a thick layer adhering to the fuel. However, such changes must be made with care; if viscosity is too low, wind-drift losses will become excessive and nothing will be gained.

From helicopters, both speed and altitude can be controlled, almost at will, so viscosity desired can be a compromise among wind drift, spread desired, and layer thickness desired. Good results have been obtained with viscosities from 100 to 1,800 cps. Even unthickened materials have performed well, but measurements have been made, which showed that a viscosity of 100 cps or more gave markedly better percentages of drop reaching the target during wind than did unthickened retardant (4). A problem here is to adjust drop speed to thicker materials. Good coverage can be obtained on a larger area by dropping from a somewhat greater height and/or speed, with some thickening. A higher salt concentration can utilize this greater spread to give more area treated per gallon at the same retardant dosage per unit of area than a concentrated drop at lower salt concentration.

With ground tankers, the only benefits from thickening are greater layer thickness on the fuel, and a longer, tighter trajectory from a straight stream nozzle. Viscosities of 200 cps or more have been found to harm spray patterns and to require excessive pressure to drive the material through long and/or small diameter hoses. An apparently effective range is from no thickening to 100 cps, but no data available to the author at this time define it more closely. Tests planned for summer 1971 should yield data upon which sound selections can be based.

3. Corrosion.

Without inhibitors, the phosphates and sulfate used in retardants are corrosive to aluminum and copper and their alloys, as well as to zinc. Ammonium sulfate is quite damaging to iron, and some damage to iron by pyrophosphate has been noted. Both the sulfate and the pyrophosphate are extremely damaging to magnesium. DAP has caused little or no damage to iron; and although it has been reported to attack magnesium, the author and his associates have been unable to observe or cause such damage.

CORROSION CONTROL

Commercial Retardant Type	Action on				
	Aluminum	Copper, etc.	Magnesium	Steel	Zinc
DAP type	N	N	N	N	S
Sulfate type	N	S	S	P	S
10/34/0					
or	SL	S	S	?	S
11/37/0					

N = Negligible SL = Slight P = Slow S = Severe

Commercially available DAP and sulfate-based retardants appear to be well inhibited against corrosive attack on aluminum, and a moderate degree of protection has been achieved with pyrophosphate (liquid)-based retardants. Thus far, only the DAP-based retardants are satisfactorily inhibited against attack on copper and its alloys.

The significance of corrosivity is hard to define in an overall sense, but certain points are clear from analysis. Damage to aluminum and its copper alloys could pose both safety and equipment-life problems in aircraft. Information on this as a result of retardant action is not readily available, but it needs to be gathered and reported. In the case of airbase facilities, differences are observed, and experience has varied from almost no damage to almost complete inactivation of facilities. Inhibited sulfate-based retardants have damaged or destroyed tanks, manifolds, and valves at several installations, but damage from inhibited DAP-based materials has been negligible. Reports on the effects of 10-34-0 types are not generally available.

If retardants are to be employed in existing ground tankers, they must not cause more than minimal damage to copper alloys and steel. This limits the practical choice to properly inhibited DAP types unless good inhibitors are developed for sulfate- or pyrophosphate-based products or unless high maintenance and replacement costs are acceptable.

B. Application Vehicles.

1. Fixed-Wing Aircraft.

A discussion of the virtues and shortcomings of types of aircraft is a study in itself and involves a great deal of opinion. Nevertheless, several observations seem pertinent.

The author believes fixed-wing aircraft carrying a retardant payload are here to stay, at least for the early phases of attack because "they get there firstest with the mostest." There is a noticeable trend toward aircraft which carry more and fly faster, in spite of the fact that reduced speed and altitude are required during effective bombing runs. The small TBM's, B-25's, and F7F's are phasing out. B-17's are being lovingly preserved because of their large payload, safety, and fairly good maneuverability. And PB4Y's and P2V's are in growing demand. Many expect C-119's and C-130's to appear on the scene. Hopefully, a general understanding of tank and discharge design will be developed soon. Much more could be said here, but the author is better equipped to tailor chemicals than to select and modify aircraft.

2. Helicopters.

Limited and experimental use of helicopters as direct attack vehicles has grown slowly since the 1950's. Even today their unique value lies in their ability to provide the most effective and rapid manpower and logistical support for firefighting efforts especially where surface access is difficult or impossible.

Although much of their appeal lies in their multipurpose capability, when they are converted for water or retardant bombing, they offer unique capabilities—complementing rather than displacing fixed-wing aircraft. Their maneuverability permits precise attack on portions of the fireline not easily reached by fixed-wing craft having to cope with terrain problems. Their ability to operate from bases near the fire permits them (at least the larger craft) to deliver more retardant (or as is usually the case today, water) per hour than can fixed-wing craft based any great distance from the fire. Although types are not discussed here, "the larger the better" is generally true for retardant application. Their use in the bombing role is increasing almost as fast as budgets permit.

C. Ground Tankers.

The evolution of ground tankers predates the scope of this review, but an examination of past efforts and the current status of their use as vehicles for delivery and application of retardant chemicals is in order.

Following successful use in aircraft, borate slurries were tried in ground tankers. Damage to hardware, difficulties in moving the thick

slurries through hoses and nozzles, and support problems eliminated this approach quickly. Algin-gel and CMC thickeners were tried. These permitted retaining thick layers of water on the fuel and they could be handled through conventional pumps, hoses, and nozzles with some difficulty. Again, support (mixing and supply) proved to be a problem, and although a significant improvement over plain water's effectiveness was achieved, lasting power was absent. Results were not considered sufficiently promising to justify the added difficulty.

The next attempt utilized a slightly thickened ammonium phosphate solution in 1964 and 1965. Support difficulties coupled with memories of past frustrations doomed early attempts with this approach, even though the material was inhibited to prevent damage to hardware and was of sufficiently thin consistency to handle well in most conventional ground tankers, hoses, pumps, and nozzles. Where used—Bureau of Land Management, Idaho; Bureau of Indian Affairs, Washington; U.S. Forest Service, Montana; and California Division of Forestry, California—results showed a marked increase in efficiency over water, but the difficulty of it all proved to be too much.

By taking advantage of retardants' greater effectiveness, the goal was, and is, to make a 200-gallon slip-on into the equivalent of a 500- to 1,000-gallon unit loaded with water. Between capital squeezes and the cost of bringing water to the units or the units to water, there still appears to be strong justification for further pursuit of this approach. Efforts are being directed toward minimizing past difficulties.

D. What Might Chemicals Do?

Chemicals should be able to increase markedly the effectiveness of men and hardware. What hardware? What chemicals? How? What is missing?

The appeal of chemical retardants lies in the fact that the work of putting 1 gallon on the fuel replaces the work of putting several gallons of water on it and sometimes can replace the work of building handlines. Airplanes, helicopters, and ground tankers have been mentioned as final delivery vehicles. For making or reinforcing line (when fuel type and terrain permit), agricultural sprayers moving at 3 to 5 or more miles per hour deserve more consideration than they appear to have received.

It is highly probable that the nitrogen/phosphorus compounds we use today offer the best "active" components for the retardants of tomorrow because of their excellent (compared with other known retardant chemistries) balance of effectiveness, weight, safety, and cost. It is equally probable that much better formulations can be tailored for the type of application vehicles to be used. Before these better formulations can be developed, more information on the requirements of the application equipment must be known. Starts

toward generating this information have been made. More studies will be made this summer and, hopefully, they will continue in the summers to follow.

But, do these lacks prevent more use of the very good materials we have today? I don't think so.

The widespread use of chemicals today is from permanent fixed-wing airbases, where support and supply are available. To be applied advantageously from helicopters and ground equipment, chemical payloads must be available to application equipment near the fire. Only recently have really promising efforts been begun to make this support less trouble than it is worth. To be so, the chemicals must be transported to the fire scene in as concentrated a form as possible, they must be mixed at high speed, and the support effort must remove a minimum of manpower from the fireline.

Two approaches are being taken today. Liquid retardant concentrates are the preferred approach by some, because of the simplicity of mixing and handling. Others are working with dry concentrates to avoid hauling water to water, and to take advantage of the much better corrosion protection and storage ease and stability. Both types depend upon ammonium phosphates as the active retardant. It appears that both types will be available in manageably sized bulk containers from which automatic, continuous mixing will be possible. An example of a completely automatic dry support unit carrying enough powder to make over 30,000 gallons is shown. (See photo) This is fine where there is a road system near the available water, but small air portable units are required to support helicopters where roads are scarce. These are scheduled for tests in Alaska during the 1971 fire season.

The justification for using retardants is that each load can be the equivalent of several loads of water. The cost of application is essentially the same. The total manpower involved is only slightly greater than that required to apply a similar quantity of water. If there is indeed a severalfold increase in effectiveness per load, then we can achieve a very real increase in effectiveness of manpower and equipment. Operational tests should be carried out to gain more precise answers to these "ifs."

Another opportunity for using portable support (developed for helicopters and ground tankers) lies with the original chemical carrier, the airplane. Really portable facilities would permit establishment of temporary operations at unimproved airstrips (with water nearby) closer to the fire. Even if retardant is delivered by air, it is more efficient to fly 1.07 pounds of dry retardant than 8.9 pounds of mixed retardant. Thus, one cargo plane could be supporting one or more air tankers, which could deliver much more to the fire each hour than if they were returning to a more distant, permanent base.

With this potential, new tactics can be developed; but personnel must be trained to execute them to realize anticipated results. Hopefully, future ventures will define some of the tactical possibilities and problems and point up changes which will ultimately be required in training programs.

E. The Far North.

Some of the characteristics which distinguish the fire problems of the North from those of the more southern States are distances, fuels, lack of roads, longer time required for initial attack, short (if any) nights, and more distance. The new developments aimed at portability eventually should contribute some relief to the distance problem and, coupled with air transport, to the problem of lack of roads. The longer time before initial attack increases the need for support bombing, and improved capability for close-in bases for the bombers multiplies their utility.

Some Arctic fuel situations are similar to those encountered in the north-central United States and are handled well with the same approaches as are used in the South, but the tundra is something else.

If we could coat the moss down to permafrost, we could probably stop a tundra fire with retardant. But we can't today. Some surfactants and wetting agents have been tried without any (to the author's knowledge) significant success. More work is justified in this area, and partial success may be possible. However, I know of no universal chemical approach to tundra fires at this time.

Implications for the ecology are twofold. What is the effect of fire? What is the effect of the retardants? They are both broad subjects, especially that of fire, and comments here will be limited to the retardants. U.S. Forest Service and Bureau of Land Management are conducting a definitive study of the subject (5), but experience and published literature already shed considerable light.

The author and others with whom he has discussed the subject see little effect on land except a localized fertilizing action. What happens in water when the retardants are inadvertently applied to a stream or lake deserves closer examination. It is difficult to imagine how the relatively small quantities used can cause a serious eutrophication problem from the noncontinuous introduction, characteristic of fire control actions. The questions that must be answered seem to pertain to acute toxicity at or close to the time the retardants are introduced into wild water. DAP-based retardants were found to have a 48-hour TLM of 46 p.p.m. (parts per million) for rainbow trout and 25 p.p.m. for bluegills in one study (6).

The literature shows ammonia to be harmful at concentrations of from 5-15 p.p.m. (7, 8, 9) and safe under 2.0 p.p.m. for exposures

under 96 hours. The DAP-based retardants contain about 21 percent ammonia, so the observed bluegill toxicity of 25 p.p.m. involved an ammonia concentration of slightly over 5 p.p.m. and the trout toxicity of 46 p.p.m. involved an ammonia concentration of about 9.7 p.p.m. Both of these are within the reported dangerous range for ammonia, and it appears that ammonia can account for the toxic contribution of the retardant. This is a fairly high concentration, and it is difficult to see how it could be reached on any broad scale with retardants—especially since they are not usually introduced into water except in the small quantities required to tie a fireline to a stream or lake. Very localized kills could be caused in small streams, and very small impoundments of standing water could be harmed. It is hard to visualize any broad ecological impact from retardants.

In summary, the path has been traced to present practice in the use of retardants to fight wildfire. The characteristics of the components of complete retardants have been discussed. Ways in which retardant use could be expanded beneficially have been explored. Needs and trends were analyzed. The problem of tundra was found to be still with us. And it was suggested that the potential for significant ecological damage from the use of retardants was extremely unlikely.



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Values protected in interior Alaska

Abstract

The Bureau of Land Management in Alaska allocates fire control resources during critical situations according to a plan that considers resource values, fire danger, and numbers of men committed to fires. Values were assigned by resource managers according to a standard point value system. Justification of fire expenditures must consider values saved. Graphs are attached which illustrate the relationship of costs, losses, and values saved at varying levels of input.

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We are often asked, "Why do you fight fires in Alaska, particularly when the costs are so high?" There is also an implied portion of the question, "and when the values are so low." This is essentially a question for the land manager rather than the fire control specialist for it is he who must decide how much protection he needs and can afford. Over the years, land managers have developed policies and procedures to guide fire control efforts in Alaska. In answering the question I will outline the Bureau of Land Management's (BLM) fire control policies, priority system, and fund allocation rationale. I will also touch on how the present state of knowledge affects our decisionmaking, and how future knowledge will be integrated into our program.

Policies

First of all, let me explain that most of the wildfires BLM fights in Alaska occur on lands administered by agencies other than BLM. Therefore, we take action on these fires at the direction of the managing agencies. Sixty-nine percent of the wildfires BLM fought in 1969 and 1970 occurred on State and private lands covered by a reimbursable contract. Over 95 percent of these fires were man-caused and occurred primarily on high value lands near population centers. BLM also took action on fires on lands of Bureau of Sport Fisheries and Wildlife, Bureau of Indian Affairs, and National Park Service under cooperative agreements. Each of these land management agencies has its own objectives, and BLM is serving as the Department of Interior's fire department in these instances. On the public lands, which

comprise about 85 percent of the 220 million fire-prone acres of interior Alaska, however, BLM is the managing agency as well as the protection agency. Our policies concerning fires fought on these lands are:

U.S. Department of the Interior.—"Hold fire losses to the minimum possible consistent with the least expenditure of public funds necessary to provide adequate protection of the resources in the public interest." One way of expressing this policy as a formula is: Costs plus losses = minimum.

Bureau of Land Management.—"1. Control all fires burning in the higher-value areas.

2. Control all fires burning in the lower-value areas when possible and when the fire potential on higher-value areas is low enough to allow risking BLM capabilities."

Priority System

To implement these policies, we have a priority system or action plan by which we allocate men and resources to going fires and to readiness reserves. Since we don't have the capability to fight all fires during severe years, we use three determinants to ration our forces: resource values, fire-danger rating, and number of men committed to fires. During periods of low fire activity, we take action on all fires. When weather is critical and we already have large numbers of men on fires, we hold back a reserve to take action on fires in the highest value areas. These areas are along the highways and near villages. In years like 1968 and 1969, sheer numbers of fires overwhelmed us and we had to let some of the fires in the lower value areas go. With 4,000 men deployed on the 1969 Swanson River fire near Kenai, we had only very limited initial attack reserves available for new fires. As a result of this system, one group of fires north of Tanana in 1969 burned together to form a complex of 1 million acres. Another fire burned during the period of May through October from Chalkyitsik to Fort Yukon, a distance of 44 miles. Fires in 1969 produced an estimated 145,000 cubic miles of smoke which persisted from mid-June through mid-July.

These experiences have shown us that large, uncontrolled wildfires eventually become a threat to life, property, or military installations. Regardless of what is burning, the smoke that drifts from them covers high-value areas and stops aerial detection and air attack on new fires. We have not been able to identify any area where fires can safely be left to burn without serious consequences and high costs.

The only effective means of control we have is to take all-out action on these fires while they are small and controllable. Wildfire is not a precision tool that can be allowed to burn to certain predetermined limits, then stopped. It is not like a gas stove that can be turned up, then turned down when the pot starts to boil. It is more like an atomic reaction that we either stop at the beginning or don't stop at all. Prescribed fire, on the other hand, can be a highly useful management tool when used within proper limits.

Of interest here is the resource value determinant of the action plan. This is a component of the Bureau's Normal Fire Year Planning System. Areas of similar value are delineated on a map encompassing all ownerships in the protection area. Value components are then rated by resource managers with a standard point system. Areas with the highest point total receive the highest relative ratings. Elements considered are soil, watersheds, timber, recreation, wildlife habitat, grazing, and potential for development. The weaknesses in this rating system are the lack of resource inventories in most of Alaska and the lack of knowledge of the effect of wildfires on certain components such as soil, watersheds, and fisheries.

Fund Allocation Rationale

Although our action plan guides and helps us to implement suppression policy, it is more difficult to quantify guides to action in the least-cost-plus-damage policy. Therefore, we have prepared cost-benefit graphs to illustrate the relationship of fire control cost to values protected. Further discussion of the concept is found in K. P. Davis (p. 484-487).¹

The graphs were based on a formula derived from the basic policy expressed as follows:

1. Cost plus loss = Minimum

2. $\frac{\text{Cost plus loss}}{\text{Values saved}} = \text{Cost/benefit ratio}$

or

3. $\frac{C \text{ plus } L}{N \text{ minus } L} = R$

where:

R = Ratio of costs to benefits. A value less than 1.0 is beneficial. 1.0 is the break-even point.

C = Average annual protection costs including both presuppression and suppression (\$).

L = Average annual loss (\$). In this analysis, it is derived from estimated average acreage losses at various sustained funding levels times an estimated average loss figure per acre.

N = Average annual loss (\$) if no fire control action were taken. Derived from estimated no-control burned acreage times an estimated average loss figure per acre.

In order to prepare these graphs, basic assumptions and estimates concerning the three dependent variables considered had to be made:

¹ Kenneth P. Davis. *Forest fire: control and use*. McGraw-Hill Book Co., Inc., New York. 1959.

1. Values saved

There are values to protect. If there are none, then no protection is justified. The emphasis on values *saved* must be equal to the emphasis on costs and losses. In order to calculate values saved, an estimate must be made of burned acreage if there were no fire protection. We estimate this would be two to four times the current average annual burn of 800,000 acres in Alaska.

2. Value per acre

The estimated per-acre values of burnable resources must be expressed in dollars in order to make comparisons, since fire costs are readily quantifiable in these terms. For interior Alaska this requires estimates of discounted future values of items such as timber, estimates of offsite damages such as air and water pollution, and estimates of intangible values such as loss of scenic beauty or critical wildlife habitat. Since comparable market transactions are scarce or lacking for much of the interior, alternative dollar level estimates must be used for break-even comparisons.

Estimates must be made of the degree of loss due to wildfire. For example, not all the merchantable timber in a commercial stand is necessarily destroyed by a wildfire. There may be salvage value in the stand for a time after the fire. Similarly, the base land and mineral values are not lost, only the burnable surface resources.

3. Protection effectiveness

The effect of varying cost levels of protection must be estimated. The current average cost and loss level is known. Loss levels with zero protection and with very high intensive protection can be made fairly readily. This gives three points on the curve. Precise estimates of the intermediate levels of protection are more difficult to plot on the curve.

Statistical averages of costs and losses covering a minimum of 10 to 20 years must be used since the effect of weather in any given year is so variable.

Charts 1 to 4 using the above criteria illustrate the following points:

1. With no protection, there are measurable costs to the landowner or the public that depend on the estimate one places on average burnable resource value. For example, chart 2 shows that with no protection, there is a \$5.5 million loss at the \$2 per acre level.
2. With too much protection, costs exceed benefits as shown in chart 2.
3. Depending on one's estimate of values, optimum levels of protection can be determined. For the assumptions used, chart 3 shows the optimum level of protection cost to be about \$7 million.

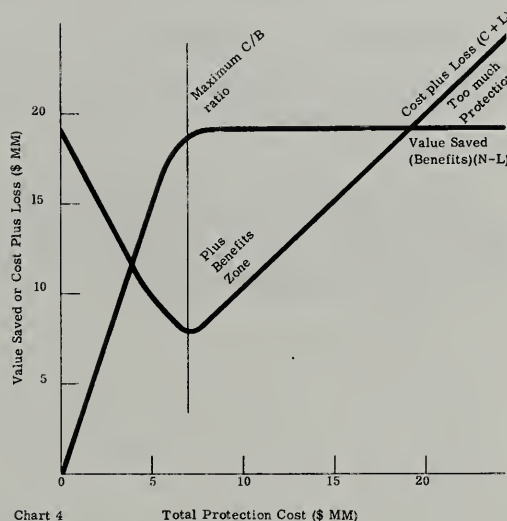
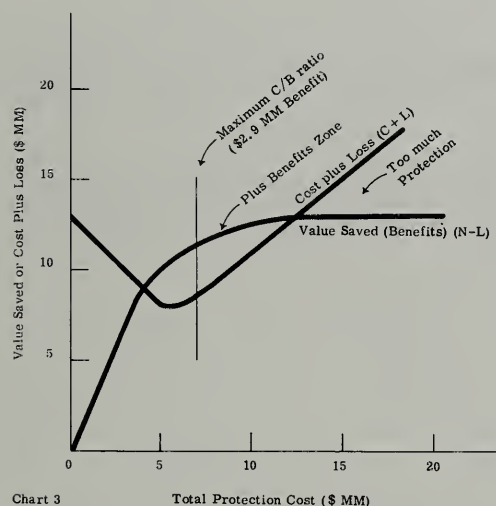
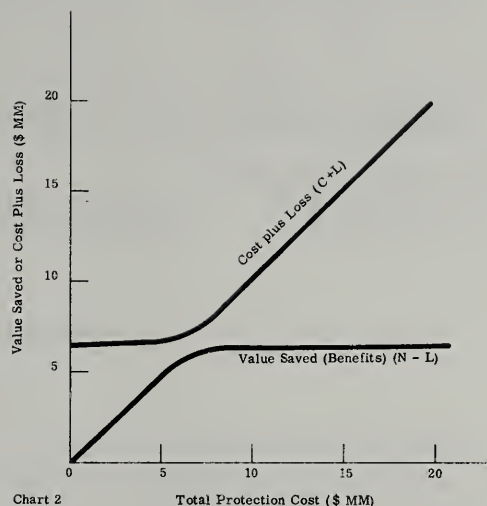
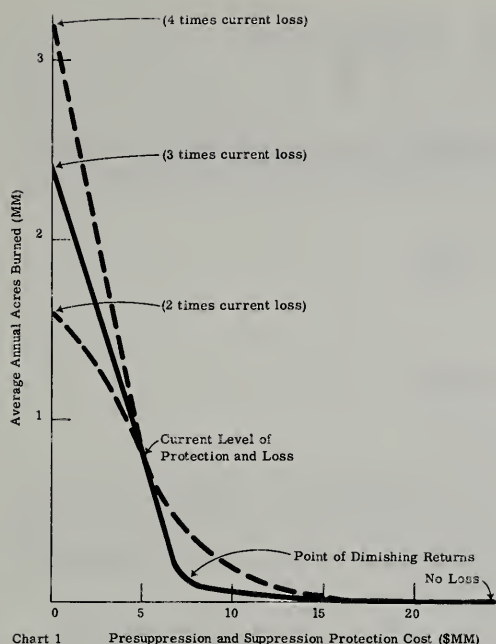


Chart 1.—Estimated acres burned at varying Protection Cost Levels on the Bureau of Land Management protection area in Alaska. The curves illustrate examples of three estimates of acreage loss with no protection (2x, 3x, 4x). Illustrated also are two estimated levels of acreage loss at the \$5 million to \$15 million cost levels.

Chart 2.—Cost-Benefit Analysis at \$2/acre Resource Value. Since the curves do not intersect, the chart illustrates that costs exceed benefits at an assumed average per acre value of \$2/acre for burnable resources and all on-site, off-site, intangible, and future values.

Chart 3.—Cost-Benefit Analysis at \$4/acre Resource Value. The curves intersect and indicate positive benefits from approximately the \$4 million cost level to the \$12 million level.

Chart 4.—Cost-Benefit Analysis at \$6/acre Resource Value. The large zone of positive benefits between the curves illustrates the effect of higher estimates of per acre value.

By comparing charts 2, 3, and 4, one can see that the average value of resources saved has a very large influence on the amount of protection cost that can be justified. Admittedly the values used in constructing the graphs are based on a wide range of variables and intangibles. However, the process of constructing the graphs forces one to quantify his particular estimate of the dependent variables.

Summary

In summary, we have discussed why we fight fires in Alaska. The basic answer is that we estimate that the values of resources protected are great enough to justify protection costs. This estimate is based on a number of factors that require more research and study:

1. Effects of fires--positive as well as negative.
2. Inventories of resources.
3. Better estimates of resource component values based on detailed economic analyses.

In the meantime, our approach is to provide a level of protection that will limit damage to the burnable resources and thus preserve the options of future land managers and decisionmakers.

White spruce stringers in a fire-patterned landscape in interior Alaska¹

Abstract

In a south-facing subbasin of Caribou-Poker Creek Research Watershed near Fairbanks, several mature white spruce stringers, apparent relics of extensive stands that have escaped fires, were studied.

Tree-ring investigations show that the mature spruce stringers have remained fire-free for at least 200 years, whereas the adjacent areas show evidence of burning every 40 to 60 years. The tree patterns, composition, and density of the spruce stringers are quite homogeneous, but those of the adjacent areas of young birch-spruce show large variations both within the same area and among different areas. The previously burned areas indicate a long-term cycling effect (40 to 60 years) which seems to maintain or perpetuate a birch-spruce community. The stringers are associated with a slight depression in microrelief. Soil temperature at the 1-inch depth showed the previously burned site was a maximum of 7° F. warmer than the stringer site during summer 1970. Although the summer of 1970 was exceedingly wet and overcast, moisture conditions on the forest floor of the stringers were much higher than in the adjacent areas. As determined by Colman blocks, the soil moisture percent by volume of the surface horizon in the stringer site averaged 61.5 percent for summer 1970; the previously burned area averaged 40.2 percent during the same period. The higher soil moisture content of the stringers, along with possible shielding of these protected areas from winds during fire conditions, would seem to be significant factors in keeping the spruce stringers fire-free.

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Much of the forested landscape of interior Alaska is a mosaic of tree species owing to the great number of forest fires which have swept through the area in the past. Low precipitation, long hours of sunlight in the summer, highly flammable ground cover, trees which provide good fuel, and frequent lightning storms combine to make a high fire hazard (5). This condition is augmented on the south slopes which receive more solar radiation and are

¹Parts of the data used in this study were supported by the National Weather Service (ESSA E 248-69-N) and the Corps of Engineers (DACS 85-70-C-0016).

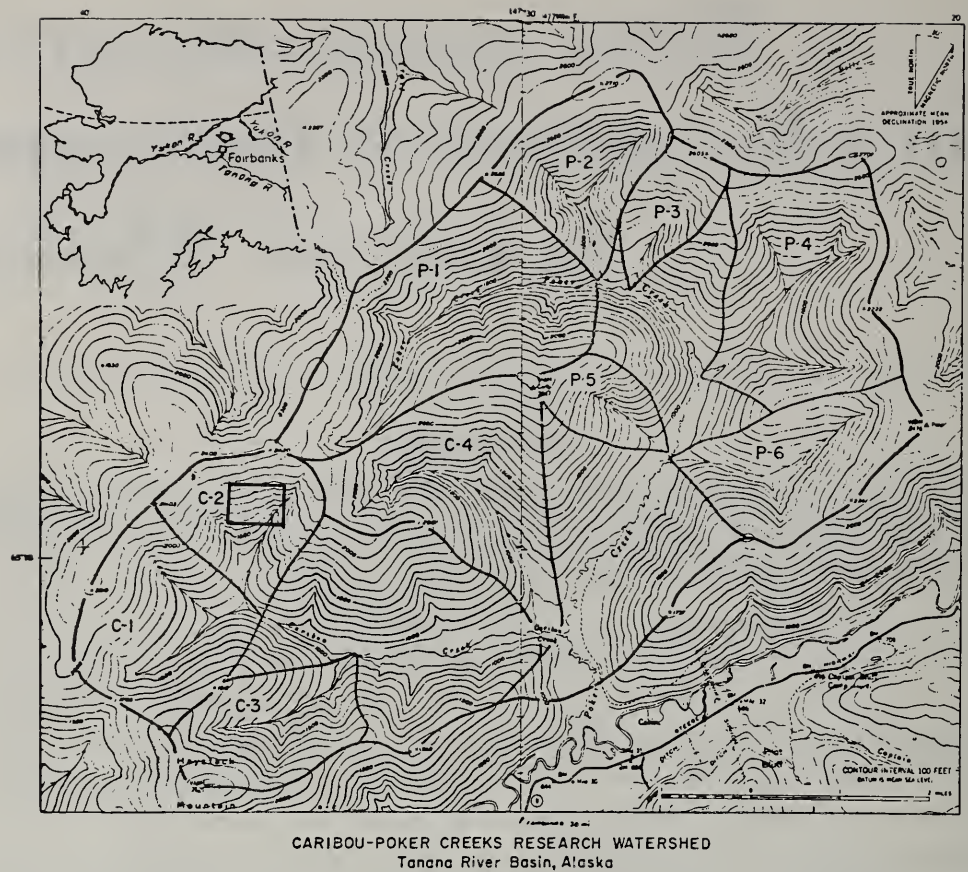


Figure 1.—Map of the study area. See square in subbasin C-2.



Figure 2.—Overview of mature spruce stringer pattern. View is north, subbasin C-2.

therefore warmer and drier. The patterned landscape on south-facing slopes may be intensified by the relative ease with which birch and aspen seed can be disseminated by the wind. Furthermore, these seeds appear to germinate more successfully than conifers on areas which are open to the drying agencies of wind and sun (4).

Several mature white spruce stringers were studied with the adjacent burned areas on a south-facing slope in the Caribou-Poker Creeks Research Watershed 30 miles north of Fairbanks (7) (fig. 1). The geology of the area is chiefly Precambrian schist and gneiss of Birch Creek schist formation (8). The rocky and poorly developed surface soils are usually silt loams which have formed in loess parent material. Patterns of the stringers were delineated, and composition and density were determined for burned and unburned areas. The two previous severe fires in the burned areas were dated, and a study was made to pursue possible reasons for the mature spruce stringers remaining fire-free.

Sites and Methods

The stringer pattern occupied the midsection of a 1,200-foot south slope (figs. 2 and 3). Six mature spruce stringers and the adjacent previously burned areas were investigated using a line transect at 2,100-foot elevation. At the 2,100-foot contour, the mature stringers appeared as definite stringers, and all were separated by burned areas (see fig. 4). Further downslope, some of the stringers coalesced into one connected patch of trees.

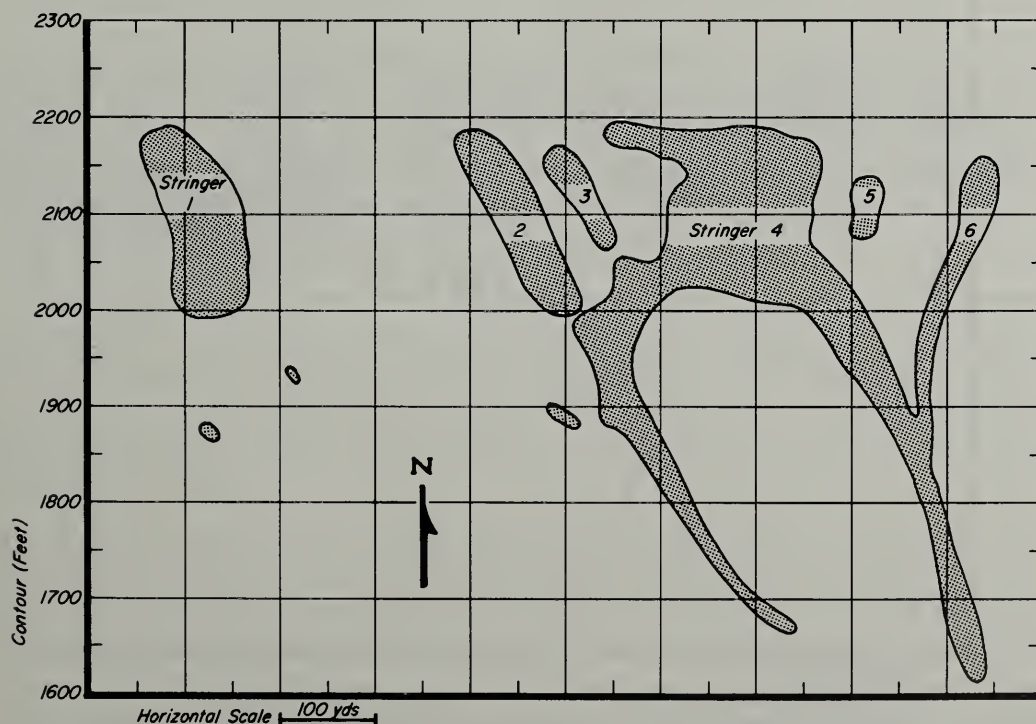


Figure 3.—Mature white spruce tree pattern in the study area.

A ground reconnaissance of the area was made. Distances were paced off and maps were drawn to scale. An increment borer was used to take cores from which growing trees were dated. The cores were stored in plastic straws which were sealed tightly in the field by heating with a match and pressing each end together. The cores were wet and the rings counted. In only a very few instances were the rings so close together as to cause difficulty in counting. The number of rings counted in a core was assumed to be the age of the tree. To determine the age of fire-killed spruce, the trees were cross-sectioned with a saw and the rings counted.

Tree density was obtained by counting all the trees within a randomly chosen 120- by 120-foot (1/3-acre) plot. For the burned communities, names of the species are denoted in order of dominance, on the basis of both height (community dominance) and density (abundance dominance).

A study site representing the mature spruce was located in stringer 1 and a site representing the burned areas in burned area 1. Vegetation and soil profile descriptions and soil moisture and temperature determinations were taken at the two sites. The Troxler surface neutron meter was used throughout the summer to monitor the moisture content in the upper 6 to 12 inches of soil. Colman block units were used to measure soil temperature and also the soil moisture within the various soil horizons. The Colman blocks were calibrated in the laboratory by soil weight and volume using undisturbed soil cores from the field. The volume-based data are used for comparison with the neutron meter determinations.

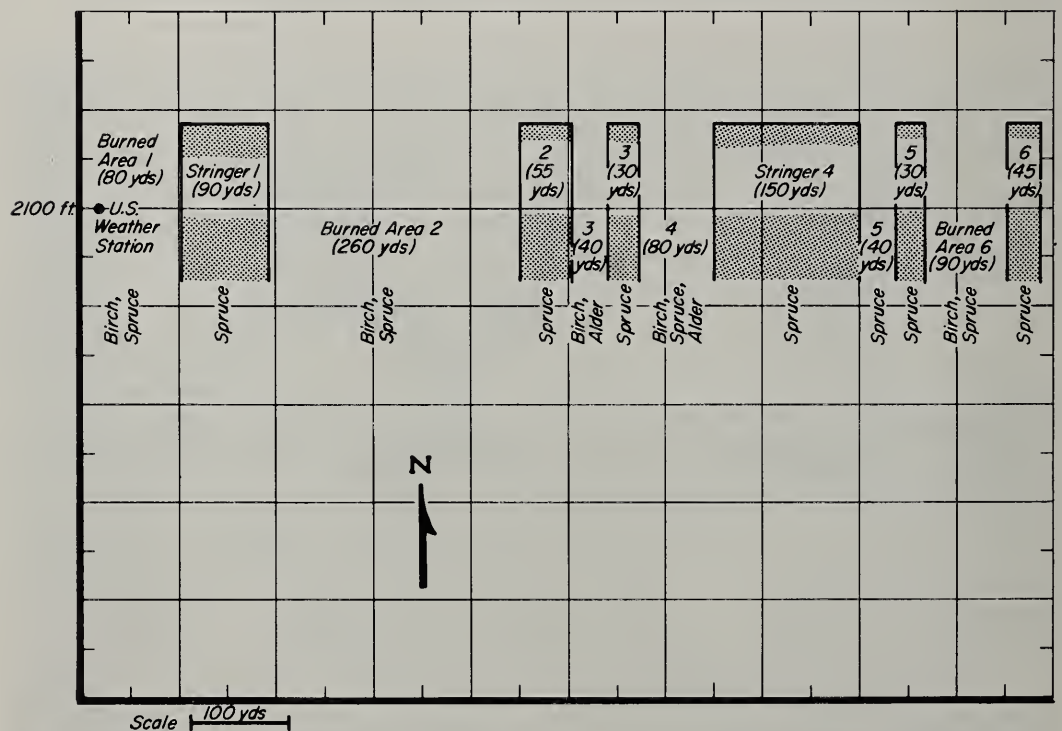


Figure 4.—Schematic diagram at the 2,100-foot contour depicting the six stringer communities and the adjacent burned areas.

Results and Discussion

The tree patterns of the mature white spruce stringers are shown in figure 3. The composition and density of the understory (table 1) were uniform among stringers and observed to be uniform within stringers. The spatial arrangement and the age of the dominant spruce and birch trees were also observed to be rather uniform both within and among stringers. However, the density of the spruce varied between 370 and 121 trees per acre. Table 2 presents the d.b.h. of all spruce trees in a random plot sample from stringer 1. Trees of all sizes are represented which indicate good regeneration of the spruce forest. Forty-four percent of the spruce trees had d.b.h. greater than 10 inches and 77 percent had d.b.h. greater than 6 inches. One or two periods of struggle and release were observed from most of the large spruce cores (2).

The composition, density, and age of the trees among burned areas were relatively heterogeneous. Burned area 5 is a spruce community with a density of 658 spruce, 88 aspen, and 82 birch per acre with scattered willow and alder (table 1). Burned area 4 is a birch-spruce-alder community with 725 spruce, 685 birch, and 403 alder per acre with scattered aspen and willow. The composition and density were also highly variable within the same general area. Several age groups from seedlings to 35 years were found for white spruce in the burned areas (table 3). On the other hand, dominant birch in each burned area was 30 to 38 years old. Another similar trend is that those 30- to 38-year-old birch are the oldest living trees in each of the burned areas, and spruce has seeded-in at various times later. This is consistent with other findings (4).

From the above information, it seems reasonable to conclude that the last severe fire in the Caribou Creek area was approximately 40 years ago, about 1930. Man's activity from mining and trapping began in the early part of the 20th century. In 1907, C. C. Covert (3) began streamflow measurements near the mouth of Caribou Creek. There was little activity in the Fairbanks district prior to the gold discovery of 1902.

A few widely scattered fire-killed spruce remained standing in the burned areas. Table 4 shows that the oldest fire-killed spruce was 65 years old when destroyed by the last severe fire in approximately 1930. This would likely indicate that the severe fire previous to 1930 may have been 65 years earlier, or approximately 1865. This latter date would be previous to white man's activity in the basin.

In the spruce stringers, however, the average age of mature spruce trees was 193 years, and the oldest tree sampled was 208 years (table 1). This indicates that no severe fire has invaded the stringers within the past 200-plus years. Although old living trees were not cut down to look for fire scars, no other evidence can be found that even moderate fires had penetrated these stringers in the past. A few old logs in a rotted state are evident on the forest floor.

TABLE 1.—The density and age of dominant trees in the spruce stringers and burned areas

Area	Community	Density (trees per acre)					Age of dominant trees (years)
		Spruce	Birch	Aspen	Willow	Alder	
Stringer 1	Spruce	128	10	—	(¹)	(²)	185
Stringer 2	Spruce	225	16	—	(¹)	(²)	194
Stringer 3	Spruce	370	8	—	(¹)	(²)	160 ³
Stringer 4	Spruce	121	20	—	(¹)	(²)	208
Stringer 5	Spruce	190	3	—	(¹)	(²)	220 ³
Stringer 6	Spruce	168	8	—	(¹)	(²)	190 ³
Average		201	11	—	—	—	193
Burned area 1	Birch-spruce	788 ²	384	96	(¹)	134	38
Burned area 2	Birch-spruce	523	285	(¹)	(¹)	142	35
Burned area 3	Birch-alder	580 ²	226	(¹)	(¹)	258	32 ³
Burned area 4	Birch-spruce-alder	725	685	(¹)	(¹)	403	32
Burned area 5	Spruce	658	82	88	(¹)	(¹)	35 ³
Burned area 6	Birch-spruce	1,096	161	(¹)	(¹)	(¹)	30 ³
Average		728	320	—	—	—	34

¹ Scattered.² Understory.³ Estimated from tree diameters.

TABLE 2.--Diameter breast height of all 48 spruce trees located in a random 150- by 105-foot plot in stringer 1 (ascending order)

Tree number	D.b.h.	Tree number	D.b.h.	Tree number	D.b.h.
---Inches---		---Inches---		---Inches---	
1	Seedling	17	7	33	11-1/2
2	Seedling	18	8	34	12
3	1	19	8	35	12
4	1	20	8	36	12
5	2	21	8	37	13
6	3	22	8	38	13
7	3-1/2	23	9	39	13
8	3-1/2	24	9	40	13
9	5	25	9	41	14
10	5-1/2	26	9	42	14
11	6	27	10	43	14
12	6	28	10	44	15
13	6	29	10	45	15
14	6	30	10	46	16
15	6-1/2	31	10	47	18
16	7	32	11	48	18

Lutz (5), in his classical study of the ecological effects of fires in Alaska, states that the isolated stands of a few acres of white spruce (the upland stringers) and even scattered spruce trees are relicts of extensive stands that have been destroyed by fire. Scattered mature trees were found outside the study area to the west. No evidence can be found in the burned areas to indicate that these areas were or were not once extensive stands of mature white spruce. How long these areas have been occupied by young communities of birch or birch and young white spruce is unknown, but it is presumed to be a long time.

The burned sites were evidently birch-white spruce communities when they last burned some 40 years ago. Aspen evidently is not a strong competitor with birch on this particular site. The succession seems to be a reoccurring cycle, as a severe fire every 40 to 60 years would appear to perpetuate a new birch-spruce subclimax community. After a fire, birch comes in first, then spruce gradually seed-in over a period of 20 to 30 years (table 3). At 40 to 60 years, before the spruce begin to compete with the birch for dominance, a severe fire occurs and starts the cycle over again. Maisurow (6) discussed the cycle where succession is continually being set back by the reoccurrence of fire.

TABLE 3.—Forest communities and age of dominant birch and spruce in the burned areas

Burned area	Age of dominant trees		Comments
	Birch	Spruce	
----- <i>Years</i> -----			
1. Birch-spruce	38	30-35 ¹	Birch established first; gradual entry of spruce.
2. Birch-spruce	35 ¹	33	Birch established first; gradual entry of spruce.
3. Birch-alder	32 ¹	(²)	Birch is dominant; spruce understory.
4. Birch-spruce-alder	32	15-20	Birch is dominant; gradual entry of spruce.
5. Spruce	35 ¹	20-25	Scattered birch established first; spruce came in gradually.
6. Birch-spruce	30 ¹	20-25	Scattered birch established first; spruce came in gradually.
Average	34	20	

¹Estimated from tree diameters.²Seedlings.

TABLE 4.—Age of fire-killed spruce trees which were still standing in 1970 in the burned areas

Tree number	Age of dead tree	Comments
1	65	These trees were apparently killed in the last severe fire which was about 40 years ago. The oldest trees had been growing for 65-70 years at the time of that fire.
2	57	
3	53	
4	52	
5	48	
6	47	
7	34	
8	28	

An interesting question concerning the isolated spruce stringers is how they have managed to remain relatively fire-free in an overall fire-prone landscape. They appear totally unaffected by the many fires which have presumably burned in this area in the past. In attempts to study this problem, papers (1, 5) mentioned the presence of upland stringers in a fire landscape. However, no reasons were offered as possible explanations for their existence in a fire-dominated landscape. These stringers are found not only in the study area but have been reported common to all of the Alaska interior, especially on south-facing slopes (5).

The minute topographic features of all the stringers appear to be significantly different from those of the burned areas. The stringers are in very minor depressions or swales on an otherwise even or slightly turtlebacked slope (see fig. 5). Another unique feature is that each stringer originates at the upslope end immediately below an 8- to 15-foot escarpment and at the bottom of a small cirquelike topographic feature (see fig. 6). On the sharp escarpment and immediately above it are found only small-diameter birch and young white spruce. In stringer 1 immediately below the escarpment, several diffuse springs were found which were the source of a small streamlet which followed a channel for 150 yards before diffusing underground. Black spruce and sphagnum mosses were found growing in some of the stringers (table 5). These are typically bottom and north-slope habitat plants, as they do better on more mesic sites than the typically drier condition usually found on south slopes. The soil profile descriptions (table 6) show that the surface horizon of the stringer site has a greater capacity to store soil moisture than the burned area site. The deeper surface horizon and higher content of organic matter help make this possible.

Several Colman blocks were placed in the ground at duplicate study sites in stringer 1 and in burned area 1. Figure 7 shows that the soil temperature at the 1-inch depth in midsummer was higher in the burned area by about 5° F. Figure 8 presents temperature profiles at various depths below the soil surface. The maximum summer temperature at the 14-inch depth in the

TABLE 5.—Vegetation descriptions of a mature white spruce study site community and a previously burned site

Spruce stringer 1	
Community:	<i>Picea glauca</i>
Associated species:	<i>Picea mariana</i> , <i>Betula</i> spp., <i>Alnus crispa</i> , <i>Salix</i> spp. <i>Rosa acicularies</i> <i>Sphagnum</i> spp., <i>Pleurozium schreberi</i>
Density:	<i>P. glauca</i> — 252 trees per acre <i>P. mariana</i> — 26 trees per acre <i>Betula</i> spp. — 17 trees per acre <i>A. crispa</i> — understory <i>Salix</i> spp. — numerous small shrubs
D.b.h.:	<i>P. glauca</i> — 12 to 18 inches <i>P. mariana</i> — 3 to 6 inches <i>Betula</i> spp. — 5 to 11 inches
Height:	<i>P. glauca</i> — 55 to 80 feet <i>P. mariana</i> — 30 to 40 feet <i>Betula</i> spp. — 25 to 40 feet <i>A. crispa</i> — 6 to 10 feet <i>Salix</i> spp. — 2 to 4 feet
Age:	<i>P. glauca</i> — 150- to 180-year-old stand <i>P. mariana</i> — 60- to 105-year-old stand <i>Betula</i> spp. — 80- to 110-year-old stand
Notes: This community is a mature white spruce stringer. A continuous thick moss cover was found on this site. Grass was found especially in areas not shaded by trees. Springs were found at the head of this stringer. Alder was thick in the openings. Most of the trees were mature. Few seedlings were present here. The slope in this stringer was 12 percent.	
Burned area 1	
Community:	<i>Betula</i> spp., <i>Picea glauca</i> , <i>Alnus crispa</i>
Associated species:	<i>Populus tremuloides</i> , <i>Salix</i> spp. <i>Pleurozium schreberi</i>
Density:	<i>Betula</i> spp. — 478 trees per acre <i>P. glauca</i> — 356 trees per acre <i>Salix</i> spp. — 57 trees per acre <i>P. tremuloides</i> — 9 trees per acre <i>A. crispa</i> — abundant
D.b.h.:	<i>Betula</i> spp. — 4 to 7 inches <i>P. glauca</i> — 3-1/2 to 5-1/2 inches <i>P. tremuloides</i> — 4 to 5 inches <i>Salix</i> spp. — 3 to 4 inches
Height:	<i>Betula</i> spp. — 30 to 40 feet <i>P. glauca</i> — 25 to 40 feet <i>P. tremuloides</i> — 25 to 30 feet <i>Salix</i> spp. — 20 to 25 feet <i>A. crispa</i> — 10 to 20 feet
Age:	<i>Betula</i> spp. — 30- to 38-year-old stand <i>P. glauca</i> — 30 to 39 years <i>P. tremuloides</i> — 25 to 32 years

TABLE 6.—Soil profile descriptions of a mature white spruce study site and a previously burned site

Spruce stringer 1

Community: Mature white spruce

Elevation: 2,100 feet

Aspect: South

Position on slope: Upper one-third

Slope: 12 percent

Organic matter content: A horizon — 24 percent, C horizon — 5 percent

Soil bulk density: A horizon — 0.51 gram per cubic centimeter

C horizon — 1.17 grams per cubic centimeter

Soil profile description: 6-4 inches, live common moss

4-0 inches, partially decomposed moss, coarse root mat.

0-8 inches, A horizon. Dark brown silt. Coarse roots.

8+ inches, C horizon. Light brown gravelly loam.

Numerous channery fragments. Schist flaggy layer

8-10 inches. No permafrost down to 65 inches. High percent channery schist from 10 to 20 inches.

Burned area 1

Community: Birch-white spruce-alder

Elevation: 2,100 feet

Aspect: South

Position on slope: Upper one-third

Slope: 8 to 12 percent

Organic matter content: A horizon — 7 percent

B horizon — 4 percent

C horizon — 3 percent

Soil bulk density: A horizon — 0.90 gram per cubic centimeter

Soil profile description: 3-1 inches, dead leaves

1-0 inch, partially decomposed leaves

0-5 inches, A horizon. Weak thin platy structure.

Light brown to yellowish-brown silt loam.

5-14 inches, B horizon. Light brown gravelly loam.

Thin platy structure. Channery and flaggy fragments.

14+ inches, C horizon. Massive. Channery and flaggy fragments numerous.



Figure 5.—Photo of the stringers from the bottom of the south-facing slope of the study area. Note stringers are located in slight depressions or swales.

spruce stringer was 40° F., whereas, at the 16-inch depth in the burned area, it was 43° F. Also, there appeared to be a somewhat greater temperature spread within the profile between the two sites. These Colman blocks had been installed about June 1, with only 1 month for establishing equilibrium prior to initiation of readings. Higher soil temperatures during the summer months in the burned area are due to the destruction of the organic layer and thus less insulation of the mineral soil (9). Also, the soil moisture is lower in the burned site and would have the effect of increasing the soil temperatures because of a lower heat capacity. Higher soil temperatures would have the effect of increasing potential evapotranspiration in the burned area over that in the stringer; thus, a more droughty condition would result.

Figure 9 presents the soil moisture data from the neutron meter during the summer of 1970. This summer was exceedingly wet, as is indicated by the relatively straight curves over the entire summer. The burned area averaged approximately 23 percent moisture by volume and the stringer 35 percent for the entire summer. The soil moisture was about 12 percent higher in the stringer site than in the burned area. The higher moisture content in the stringer is presumed to result from several factors. The water-seeps at the head of each stringer are an important factor. Soil profile investigations indicate that the spruce site has a higher moisture storage capacity. The greater shading and moss layer resulting in the cooler temperatures in the spruce stands are important. The spruce forest may use smaller quantities of soil moisture for growth. Also, burning may reduce the rate of water percolation into the soil (9).



Figure 6.—Photo of the sharp escarpment at the head of stringer 4.

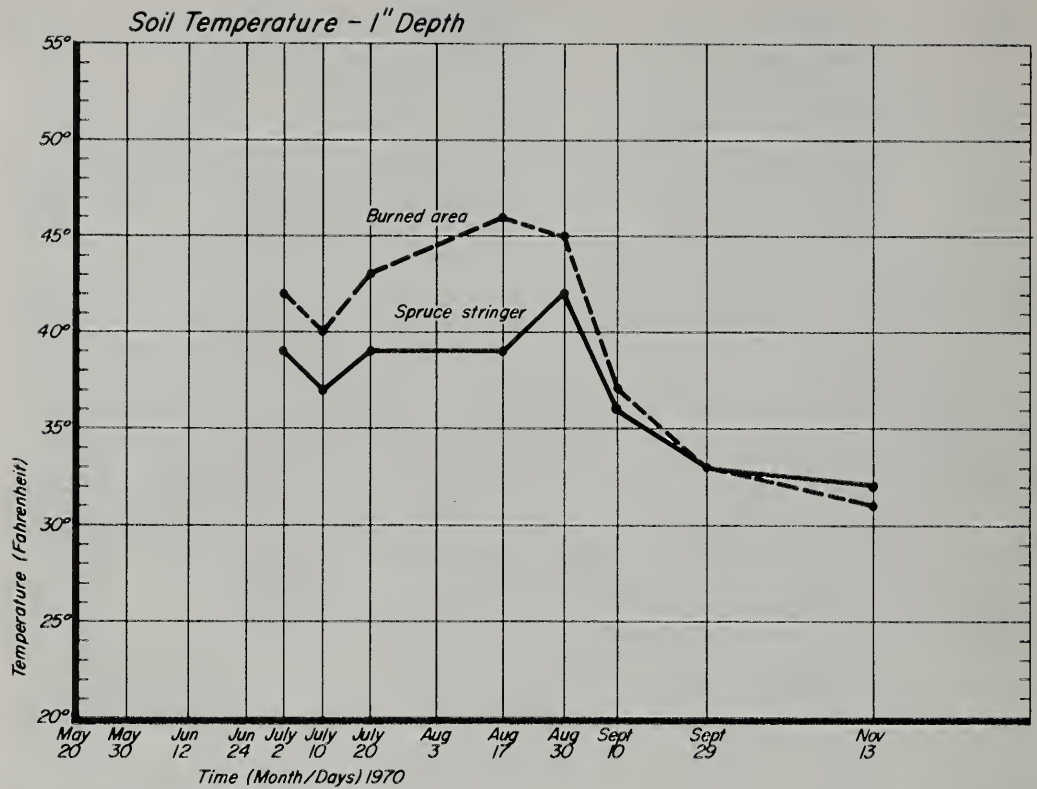


Figure 7.—Summer soil temperature data at the 1-inch depth for the stringer and the burned sites.

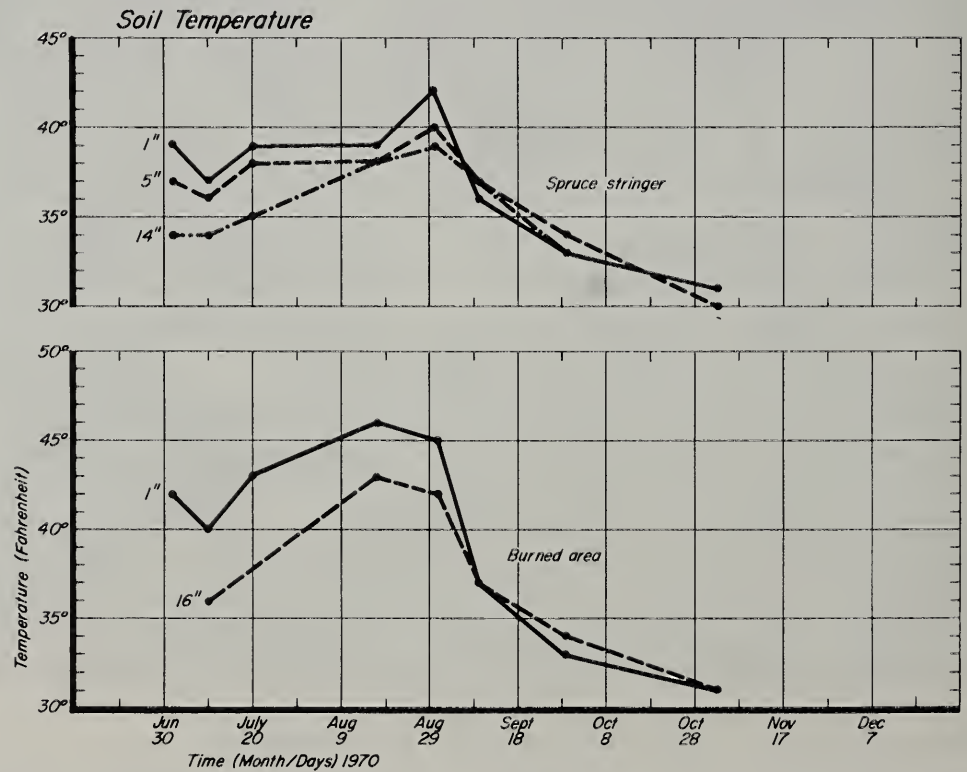


Figure 8.—Profile of soil temperatures at various depths below the soil surface for the two study sites.

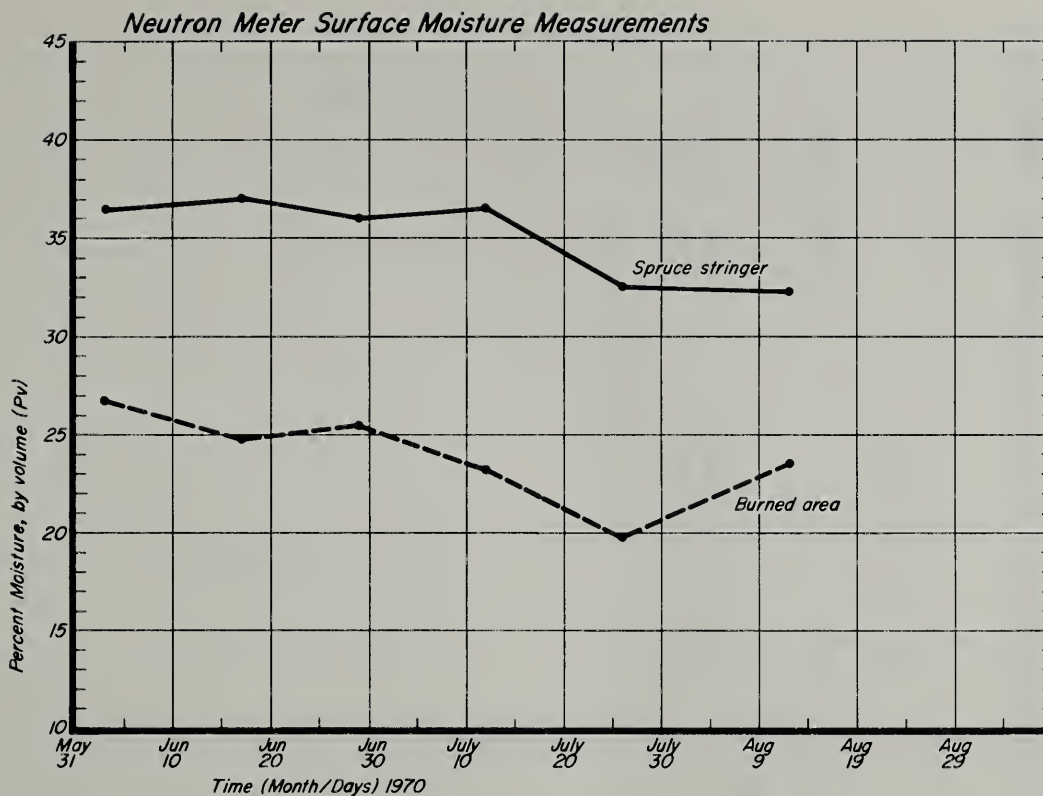


Figure 9.—Neutron meter surface soil moisture measurements of the stringer and burned sites during the summer period of 1970. Each entry is the mean of 10 determinations.

Colman blocks were also used to monitor the soil moisture throughout the profile, and figure 10 shows that the burned area averaged about 40 percent by volume and the stringer about 60 percent for the entire summer. The percent moisture obtained from the Colman blocks is substantially higher than that from the neutron meter. This discrepancy is apparently due to the manner in which each device measures soil moisture. The neutron meter measures the moisture in a given volume of space within the range of its radioactive element. The results reflect the actual volumetric soil moisture present within that "total volume." This includes soil particles, air pores, and large stones, the latter of which are quite numerous on these sites, 35 to 40 percent of total volume.

The Colman blocks measure the moisture of the soil matrix (soil particles only) in direct contact around the sensing device. For total moisture in the soil profile, the Colman blocks, unlike the neutron meter, make no allowance for stone content of the bulk profile. Thus, the reference volume is different for the two methods. When the stone content is high, an adjustment of the volumetric data for stone volume is appropriate for comparison of the two sets of data. Table 7 presents this adjustment and shows the correlation of the two methods after the Colman block data are adjusted for stones. The adjusted moisture contents are surprisingly close for the Colman and neutron meter methods, 37 and 35 percent for the stringers and 21 and 24 percent for the burned sites, respectively.

TABLE 7.—Average seasonal soil moisture content within surface 6-9 inches expressing measurement technique comparisons with stony material

Area	Percent stones in surface layer ¹	Mean soil moisture		
		Colman blocks		Neutron meter
		Percent by volume measured (on "soil" calibration)	Percent by volume (adjusted for stones)	Percent by volume measured
Spruce stringer	40	61	37	35
Burned area	35	40	21	24

¹ Estimated during field excavation, by volume.

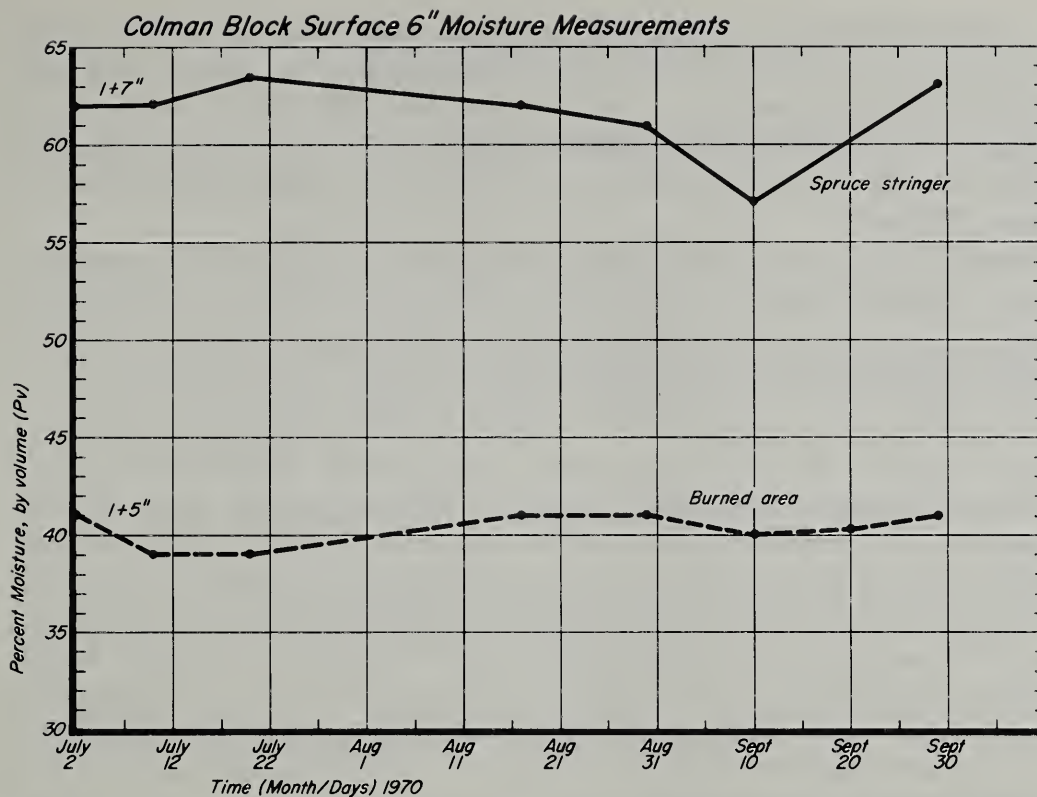


Figure 10.—Colman block surface-layer soil moisture measurements of the stringer and burned sites during the summer period of 1970. Duplicate units at 1-inch and 5- to 7-inch depths are averaged for each entry.

The combined means of the two methods averaged over the entire summer showed that the soil moisture was higher by 10 to 15 percent by total volume in the stringer than the burned area. In a dry summer this difference would be expected to be much greater.

The wetter surface soil in the stringers maintains a damp moss layer that would not be very susceptible to burning. The higher surface-layer soil moisture and the resulting greener and less combustible vegetation would seem to be a highly important factor in preventing fires being carried by the organic layer and understory vegetation as well as by the trees. This would have the effect of inhibiting fires in the stringers.

Summary

A study of mature stringers in a fire-patterned landscape in the Caribou Creek Research Watershed near Fairbanks, Alaska, has shown the stringers to be homogeneous both within and among stands in regard to spatial arrangement and age of the white spruce and birch. The understory of alder and willow was also homogeneous within and among stringers. Within and among the adjacent burned areas the composition, density, and age of the trees were found to be very heterogeneous.

The last severe fire which swept through the study area was approximately 40 years ago, around 1930. Fire-killed remnants that are still standing indicate that the fire previous to the 1930 fire may have been 65 years before, around 1865. There was no evidence that any moderate or severe fires have gone through the spruce stringers, and they appear to have been fire-free for over 200 years.

On the previously burned areas, a long-term cycling effect is indicated which seems to perpetuate a birch-spruce community. Succession toward the climax white spruce is always in progress, but because of frequent fires, the climax condition has not been approached for many, many decades.

Apparently the microrelief is a significant factor wherein the stringers have remained fire-free for so many years. All the stringers were found growing in minute depressions or swales. This topographic effect and the presence of a streamlet contributed to a higher soil moisture in the stringer sites than was found in the adjacent burned areas. The combined means of nuclear and Colman measurement methods averaged over the entire summer of 1970 showed that the soil moisture was from 10 to 15 percent higher (total volume basis) in the stringer than the burned area. The soil temperature at the 1-inch depth in the burned site was found to be 5° F. higher throughout midsummer than the stringer site. The soil temperatures at lower depths showed a similar trend.

The higher surface-layer soil moisture and the resulting thicker and wetter moss and duff cover seem to be an important factor in preventing the entry of ground fires in the spruce stringers.

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Effects of some intensive forest management practices on white spruce ecosystems in interior Alaska

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Abstract

This study reports the first 2 years' results of a thinning and fertilization study conducted in a 70-year-old white spruce forest near Fairbanks, Alaska. A 2.7-fold increase in tree diameter growth during this period was attributed to improved soil moisture, temperature, and nutrient regimes resulting from the thinning and fertilization.

Introduction

Following destruction of the existing forest by fire, dense young stands of trees may develop on upland sites in interior Alaska. In these stands, competition for light, soil water, and nutrients may be intense, resulting in decreased tree growth rates and high mortality. High stand densities reduce the amount of radiation reaching the forest floor and thus, the temperature regime.

Although intensive forestry practice in interior Alaska may be a number of years in the future, it is important to know what effect these practices may have on forest development. The objective of the present study was to apply intensive management treatments to a dense 70-year-old spruce stand believed to be of fire origin and monitor changes in tree growth and selected environmental factors regulating growth. This report summarizes the first 2 years' results.

Methods

DESCRIPTION OF STUDY AREA

The study area is located in the Yukon-Tanana uplands approximately 20 miles west of Fairbanks at an average elevation of 750 feet. Topography of the site is moderately steep (15- to 20-percent slope) and characterized by

numerous, small swales. White spruce stands, suitable for experimental purposes, occur between swales. Bedrock in the area is Birch Creek schist; soil, developing in wind deposited loess, is a deep phase of the Fairbanks silt loam.

FIELD METHODS

A 0.04-hectare control plot was established in this stand in September 1968. At this time, soil temperature units (Yellow Springs #401) were installed at ground surface, organic-mineral soil boundary, and 15, 30, 60, and 90 centimeters in the soil profile. Atmospheric temperature beneath the forest crown canopy was subsequently measured with a continuous recording thermograph and standard maximum and minimum thermometers installed in a "bird house" weather shelter (3). Precipitation (within the forest) was measured with duplicate standard 15-centimeter rain gauges and duplicate 1.5-meter-long snow depth stakes. Three randomly located aluminum neutron probe access tubes were used to assess soil moisture at 25-centimeter intervals to a depth of 1.5 meters in the soil profile. Tree diameter growth was measured using band dendrometers installed on the tree boles at breast height (6).

In April of 1969, three additional 0.05-hectare plots were established. The treatments applied to these plots were unthinned and fertilized, thinned and fertilized, and thinned only. The criteria followed in selection of trees to remain on the thinning plots were: trees of large diameter and height classes and of good vigor, and approximately equal spacing between remaining trees. In some instances, the spacing criteria resulted in codominant or intermediate crown class trees being left. Trees were felled with a chain saw leaving approximately a 15-centimeter stump. Crowns and boles of felled trees were sectioned into approximately 1-meter lengths and left on the plots.

Fertilizer was applied at rates of 112 kilograms per hectare of N as NH_4NO_3 , 56 kilograms per hectare of P as treble superphosphate, and 112 kilograms per hectare of K as KCl. Apparatus to measure environmental parameters and diameter growth was installed in the thinned, fertilized plot in the manner described for the control plot. Band dendrometers were installed on trees in the thinned only and the unthinned fertilized plots.

Since the time of plot establishment, atmospheric temperature, precipitation, and soil temperature records were maintained on a weekly basis throughout the year. Soil moisture readings were made weekly from April through September. Diameter growth measurements were made weekly from May through August. These measurements will be continued through the life of the study.

Results

Soil chemical analysis indicated that the white spruce soil is moderately acid and has N and P contents similar to selected forest soils in the Douglas-

TABLE 1.—Chemical properties of white spruce forest soil

Depth (centi- meters)	pH	N	P	CEC	Exchangeable bases			Total exchangeable bases
					K	Ca	Mg	
-----Percent ----- -----Milliequivalents per 100 grams -----								
0-2.5	5.2	0.96	0.06	94.30	0.74	22.20	2.36	25.30
2.5-5.0	4.8	.58	.07	76.00	.76	14.10	1.86	16.72
5.0-14.0	5.4	.13	.05	22.21	.19	5.66	.81	6.66
14.0-24.0	5.6	.05	.04	12.81	.13	2.89	1.00	4.02
24.0-37.0	5.8	.03	.05	14.72	.13	3.05	1.42	4.60
37.0-52.0	5.9	.03	.05	10.03	.05	2.68	1.41	4.14
52.0-67.0	6.0	.03	.04	9.46	.03	2.98	1.60	4.61
67.0-83.0	6.3	.03	.05	10.03	.05	2.59	1.36	4.00

fir region of western Washington (4) and soils supporting Norway spruce and Scots pine in Sweden (9). Exchangeable base status (K + Ca + Mg) varies from 42.02 milliequivalents per 100 grams in the surface soil (0 to 5 centimeters) to 19.42 milliequivalents per 100 grams in the subsoil (5 to 52 centimeters, table 1).

Artificial thinning reduced stand density 4.4-fold, from 6,953 to 1,568 stems per hectare. Basal area was reduced 2.6 times from 41 to 16 square meters per hectare.

By the end of the 1970 season, thinning with fertilization had increased diameter increment about 2.7 times over the control (table 2, figs. 1 and 2); thinning without fertilization increased diameter increment 1.6-fold over the control. In addition, diameter growth was detected 1 to 2 weeks earlier in thinned stands than in unthinned controls (figs. 1 and 2).

TABLE 2.—Effect of thinning and fertilization on diameter growth in a 70-year-old white spruce forest, 1970 growing season

Treatment	Cumulative diameter growth	Increase over control
----- Centimeters -----		
Control	0.07	—
Control + fertilizer	.08	1.1
Thinned	.11	1.6
Thinned + fertilizer	.19	2.7

Marked change occurred in the soil temperature regimes as a result of thinning. With one exception (average maximum air temperature May 1 to November 5, 1969, 1.8° C. higher in control than thinned plot), average atmospheric and soil temperature regimes during 1969 and 1970 for the period May 1 to November 5 were slightly warmer in the thinned and fertilized plot than in the control plot (table 3). On May 30, 1970, soil temperatures in the thinned and fertilized plot compared with the control

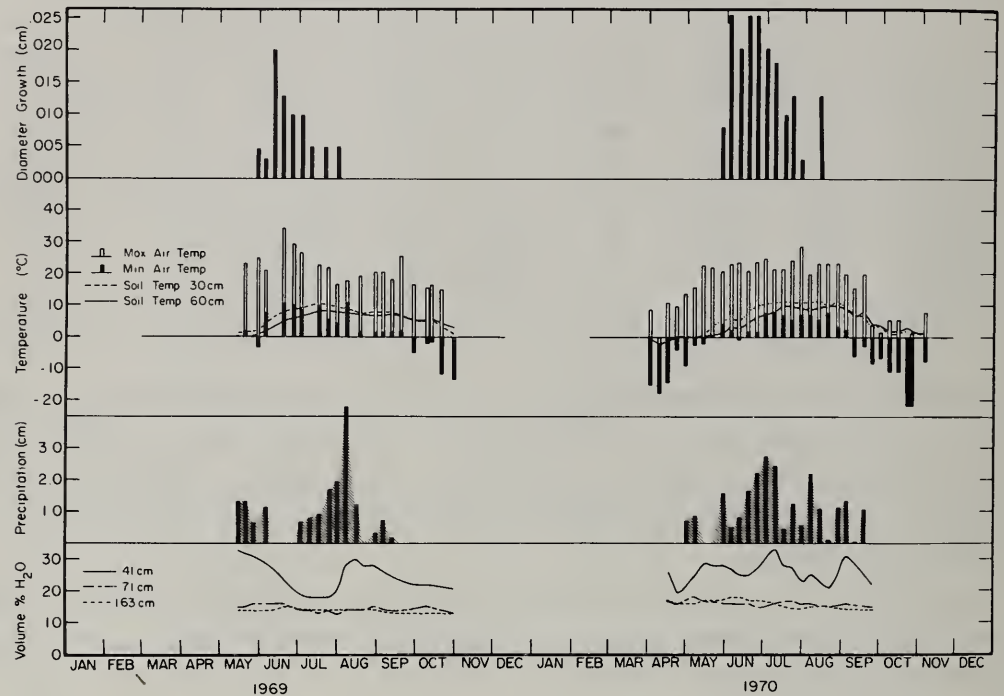


Figure 1.—Diameter growth and environmental factors in thinned and fertilized plot of 70-year-old white spruce.

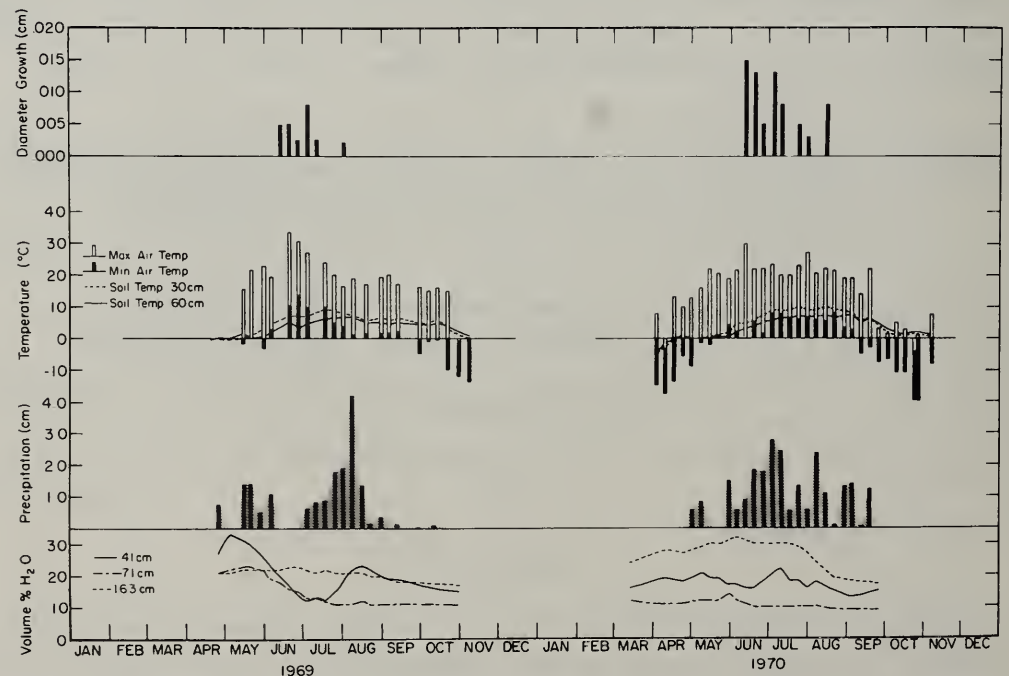


Figure 2.—Diameter growth and environmental factors in control plot of 70-year-old white spruce.

TABLE 3.—Selected temperature and precipitation data obtained from white spruce thinning plots

Time period and temperature	Control		Thinned + fertilizer	
	1969	1970	1969	1970
----- Degrees Celsius-----				
May 1-November 5:				
Average maximum air temperature	17.6	16.3	15.8	17.3
Average minimum air temperature	.9	.9	2.2	1.1
Average soil temperature, 30 centimeters	4.5	5.2	5.9	5.6
Average soil temperature, 60 centimeters	3.5	4.1	5.0	5.1
May 30:				
Maximum air temperature	22.7	19.0	25.0	21.0
Minimum air temperature	-3.4	4.4	-3.4	4.4
Soil temperature, 30 centimeters	3.5	2.0	2.0	5.5
Soil temperature, 60 centimeters	.5	.5	.5	1.5
August 28:				
Maximum air temperature	19.4	19.0	20.5	23.4
Minimum air temperature	1.5	3.4	1.5	3.4
Soil temperature, 30 centimeters	6.5	8.7	8.0	10.9
Soil temperature, 60 centimeters	5.0	7.0	7.0	10.0
----- Centimeters-----				
May 1-August 30, total precipitation	16.5	23.3	17.4	23.0

plot were 3.5° C. to 1.0° C. warmer at the 30- and 60-centimeter levels, respectively, and on August 28, 1970, 2.2° C. and 3.0° C. warmer (table 3).

Slightly more precipitation was collected beneath the thinned and fertilized stand (0.9 centimeter) than the control stand during the May to November period in 1969. Only a 0.3-centimeter difference in precipitation was detected during this period in 1970. From 5.6 to 6.8 centimeters more precipitation occurred in thinned and control stands, respectively, during this interval in 1970 than in 1969 (table 3).

Approximately 1 year following stand treatment, rooting zone soil moisture contents in the thinned and fertilized plot compared with the control plot were 9.0 and 5.8 percent higher at the 41- and 71-centimeter depths, respectively, on July 17, 1970, and 12.7 and 6.5 percent higher on August 28, 1970 (table 4). An additional feature of the growing season soil moisture regimes, which is evident in the thinned and fertilized but not the control stand, is the consistently higher, fluctuating trend at 41 centimeters compared with the lower, constant trends at the lower depths (figs. 1 and 2).

TABLE 4.—Selected soil moisture content data obtained from white spruce thinning plots

Date and depth	Control		Thinned + fertilizer	
	1969	1970	1969	1970
-----Volume percent water-----				
July 17:				
41 centimeters	12.0	16.0	18.0	25.0
71 centimeters	12.0	10.2	13.0	16.1
163 centimeters	22.0	30.2	14.0	17.5
August 28:				
41 centimeters	20.0	13.8	28.0	26.5
71 centimeters	11.0	9.0	15.0	15.5
163 centimeters	20.0	18.5	14.0	14.5

Discussion and Conclusions

Exact details on nature of the seedbed following the assumed fire are not available. However, it is probable that a combination of favorable conditions, possibly including bare mineral soil and downed and decaying tree boles, existed and contributed to extensive seed germination, seedling development, and the present fully stocked stand. At the time the present study was initiated, extensive natural thinning had occurred, leaving groups of dominant to intermediate crown class trees surrounded by dense stands of suppressed trees and dead stems.

Influence of the previous fire on mass of potential volatile nutrient elements, such as nitrogen in the forest floor and surface layers of mineral soil, is difficult to quantify. No forest floor nitrogen determinations have been conducted in the white spruce forest under consideration in the present study. However, using determinations of forest floor nitrogen content obtained in 73- and 130-year-old spruce forests in the Russian taiga (8) and determination of soil nitrogen for the 70-year-old spruce forest in the present study and a 170-year-old upland spruce forest located in the same vicinity, the loss of nitrogen from burning near the midpoint and end of white spruce forest development can be estimated.

Hypothesizing a uniformly severe burn, in which the forest floor and highly organic horizons in the surface layers of the soil profile (0-5 centimeters) are completely consumed, and the nitrogen contained therein lost, the 70-year-old forest would lose about 21 percent or 778 kilograms per hectare of the nitrogen contained in the forest floor and soil profile through

the rooting zone (68 centimeters). The 170-year-old forest would lose about 42.5 percent or 2,026 kilograms per hectare of the nitrogen contained in the same portions of the forest floor-soil profile. Depending on the severity and uniformity of burning of the forest floor and overstory, these estimates may be low or excessive. Furthermore, all the nitrogen contained in the forest floor and mineral soil is not readily available to plants but is an indication of the potential supply of this nutrient which can be released for plant use over an extended time period. The figures are, therefore, estimates of loss of a potential supply of nitrogen.

A further estimate of nitrogen deficit from burning can be obtained by considering the difference between nitrogen in the forest floor and surface 5 centimeters of soil in the mature spruce forest (170 years) and at 70 years. This amount, 1,248 kilograms per hectare or 26 percent of the nitrogen contained in the forest floor and mineral soil at 170 years, may be viewed as a nitrogen deficit from which the forest-soil system has not recovered 70 years following burning. The nitrogen deficit theoretically has been reduced to about 22 percent by fertilization. However, much of this addition may have been lost through leaching and denitrification. The amount of nitrogen contained in the soil at present will have to be determined by soil analysis. Although the deficit estimate is tentative, it is similar to estimates (1) of losses of 67 percent and 507 to 1,685 kilograms per hectare of nitrogen for burned forested areas in various geographic regions.

The relationship of forest thinning and fertilization to improved tree diameter growth rate is well documented in the literature (2, 4, 5, 7). Increased growth for thinned trees is closely correlated with improved light, soil moisture, and soil nutrient regimes (2, 7, 10, 11, 12). Because rates of soil nutrient turnover may be depressed by low temperatures encountered in taiga soils, forest fertilization in conjunction with thinning generally may be of considerable importance in stimulating tree growth.

In northern latitudes, an additional factor of considerable significance to tree growth is soil temperature. Soil temperature is critical in seasonal physiological activity of tree root systems and physical-chemical processes and soil microbial activity associated with cycling of elements required in tree nutrition. The critical role of temperature and moisture in interior Alaskan forest-soil-plant relations is emphasized by the fact that forest floor and soil organic matter are undoubtedly the principal source of nitrogen for plant nutrition. The rate at which nitrogen becomes available for plant use is controlled by microbial decomposition and mineralization of the organic matter. These processes are dependent on temperature and moisture. Increases in soil temperature and moisture content should provide more favorable conditions for organic matter mineralization and nutrient availability for tree growth. In interior Alaska, an increase in soil temperature of several degrees, as occurred in this study, may be of much greater significance to tree growth than in southern latitudes.

The control of tree density in northern latitude postfire forests may be

viewed as management of the forest-soil system for improved moisture, light, nutrient, and temperature regimes with respect to tree growth. In the present study, fire may have directly altered subsequent forest development by adversely affecting the concentration of volatile nutrient elements such as nitrogen which are contained in forest floor and soil organic matter. Fire played an indirect role in forest development by promoting the present fully stocked stand in which competition for moisture, light, and nutrients is undoubtedly intense and where a low soil temperature regime may reduce rates of nutrient cycling and inhibit tree root development. Although a more extended time period is necessary to assess the full impact of thinning and fertilization on the white spruce forest ecosystem discussed in this study, the marked changes in temperature and moisture regimes and the increase in tree diameter growth are definite indicators of the response of the forest to an improved environment for growth.

Acknowledgment

This study is a cooperative endeavor between the Forest Soils Laboratory of the University of Alaska at College and the Institute of Northern Forestry of the Pacific Northwest Forest and Range Experiment Station at College, Alaska.

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Fire, vegetation, soil, and barren-ground caribou relations in northern Canada

Abstract

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The devastation of the winter habitat by forest fires has been suggested as a possible cause of the decline of barren-ground caribou. Four areas in northern Canada were selected for studying the effects of fire on lichen rangelands. A literature review, forest cover maps, fire control records, and examination of the forests themselves indicate that fire is a natural phenomenon and not a new factor in the ecology of the region. During a period that extended from 1961 through 1964, there were 1,250 known forest fires that burned-over 5,005,872 acres of potential winter range. The cover-map data on forest age classes suggested that the amount of destruction in recent years has increased.

The standing crop of usable forage and high-value lichens was determined for six forest age classes. Destruction of the extremely slow-growing arboreal lichens by fire must be considered a serious loss of caribou winter forage.

Burning did not affect all game populations alike as shown by the densities per acre of barren-ground caribou and moose pellet groups. In forests over 120 years old, 722 caribou pellet groups per acre were found compared with only 18 per acre on the 1- to 10-year age class. There were 49 moose pellet groups per acre in the 11- to 30-year age class and only three per acre in forests over 120 years old. Moose apparently preferred habitats in early stages of succession, but barren-ground caribou favored those in later stages of succession.

Introduction

Destruction of range by fire is one of several factors which might limit barren-ground caribou (*Rangifer tarandus groenlandicus*) populations. Fires caused by lightning or man generally affect only the winter range in the taiga or northern region of the boreal forest; they are rare and usually limited on the summer range because of the mixture of wet and dry tundra and barren areas of rock or sand.

The Canadian Wildlife Service's intensive caribou research program included an evaluation of the effects of fire on four key upland lichen wintering areas within the taiga. Some primary objectives were to determine the portion of burned winter range and any increase in recent years, the effects of fire on the usable standing crops of terrestrial forage and arboreal lichens, the effects of fire on soil properties, and the effects of fire on range use by barren-ground caribou and moose (*Alces alces*).

The Study Areas

The winter range of barren-ground caribou is restricted largely to the taiga of northern Canada. It covers approximately 295,000 square miles in northern Manitoba, northern Saskatchewan, northeastern Alberta and the District of Mackenzie (fig. 1). Key wintering areas were studied intensively because data collected there would presumably be applicable to the entire winter range. Factors for selection of study areas were their importance to caribou, their inclusion of burns of various ages, and their accessibility by airplane or boat. Federal and provincial biologists with previous experience in caribou research helped select four areas of 5,000 to 8,000 square miles each (fig. 1).

The forest on the winter range is largely coniferous, with deciduous trees in disturbed regions. The major tree species are black spruce (*Picea mariana*), white spruce (*Picea glauca*), jack pine (*Pinus banksiana*), white birch (*Betula papyrifera*), tamarack (*Larix laricina*) and quaking aspen (*Populus tremuloides*).

Methods

History and Extent of Forest Fires

Information on the history and extent of forest fires came from literature pertinent to caribou and caribou ranges; fire control reports, giving number, size and causes, from 1961 through 1964, provided by government agencies in Alberta, Saskatchewan, Manitoba, and the District of Mackenzie; and vegetation cover maps of the northern Saskatchewan study area, prepared from recent aerial photographs. Forested and burned areas were classified as

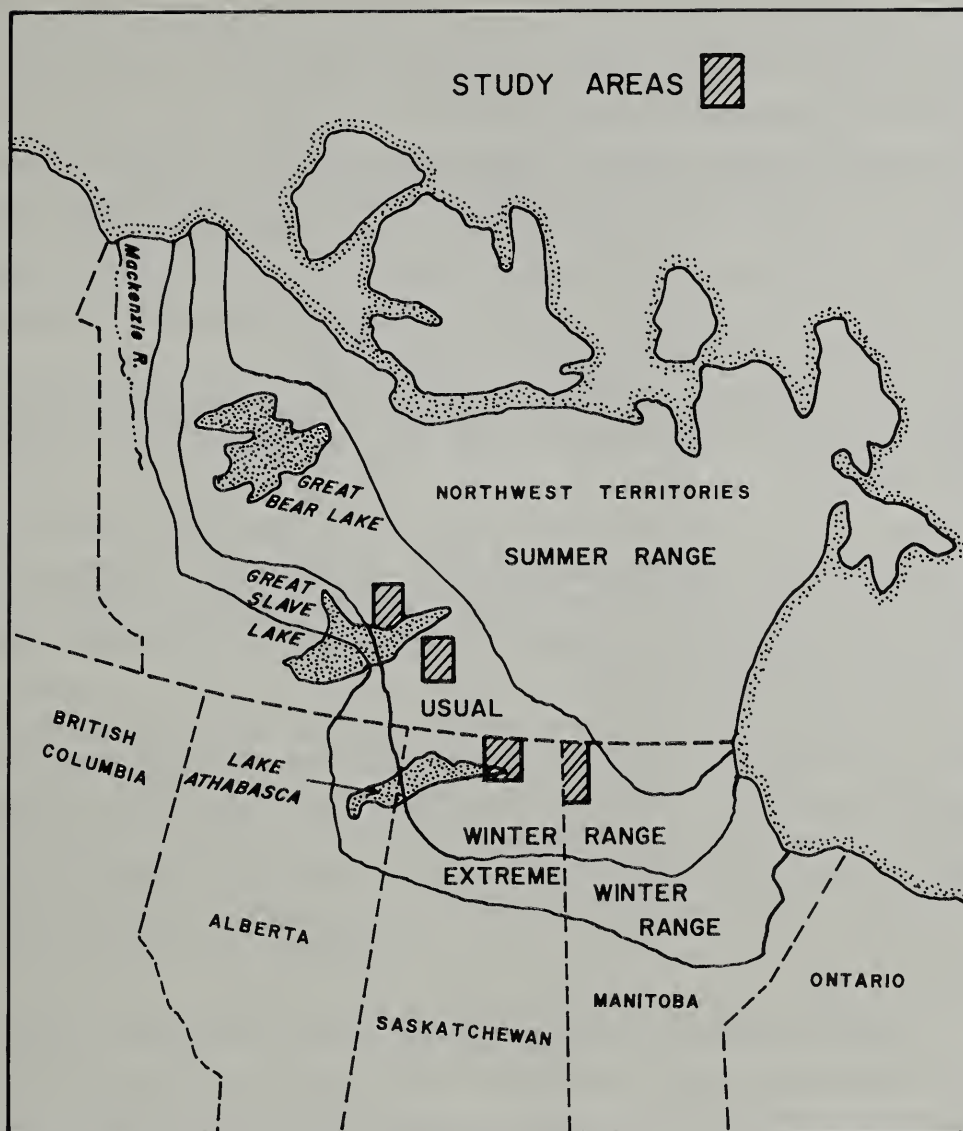


Figure 1.—Map of northern Canada showing the distribution of summer and winter ranges of barren-ground caribou and the locations of major study areas.

1 to 15, 16 to 30, 31 to 50, 51 to 75, 76 to 120, or over 120 years of age. A dot-grid overlay on the cover maps was used to determine the area of each class. The acres in an age class was divided by the number of years in that class to estimate average annual destruction.

Effects of Fire on the Standing Crop of Forage

Effect of fire on the standing crop of usable forage was determined in forest stands from each study area. A stand consisted of a spruce forest, or a seral stage of white birch or jack pine which precede spruce, on an upland

site with similar floristic composition and cover throughout. Forest stands were divided into six age classes: 1 to 10, 11 to 30, 31 to 50, 51 to 75, 76 to 120, and over 120 years. Each stand was sampled by the weight-estimate method of forage inventory (39, 15).

The usable standing crop was measured on 126 forest stands in 38 locations on the study areas. Each stand contained five 100-foot-square sites located, if possible, on the north, south, east and west slopes and on a level area. The sites represented, as nearly as possible, the slope or level area under consideration. Sites were 0.1 to 2 miles apart, depending on the topography and size of the forest stand in which they were located.

Each site contained 16 randomly selected circular sample plots stratified so that four fell into each quarter of the site. The sample plots covered 9.6 square feet each.

Forage in the circular plots was clipped and weighed, or its weight was estimated in grams, to determine how much usable standing crop was available. Clipped forage was separated into species or groups before it was weighed on a spring scale. Actual and estimated weights were recorded to the nearest 5 grams of green weight.

The current growth of forbs, grasses, grasslike plants, and deciduous shrubs was weighed. Leaves were removed from such evergreen shrubs as mountain cranberry (*Vaccinium vitis-idaea* var. *minus*) and common Labrador tea (*Ledum groenlandicum*). Lichens were removed only to the level where decomposition of the podetia was first observed as caribou probably do not like the pungent odor of decaying podetia. Bryophytes were not included as they are probably eaten only incidentally with other forage.

Green weights were converted to air-dried weights. Daily samples of each major forage species were stored at room temperature in 100-gram amounts until no weight loss could be detected. Lichens could be compared only on an air-dried basis since their moisture content varied from 20 to 85 percent with weather conditions. Workers were trained to check estimates against actual weights before fieldwork began, and field estimates were checked daily throughout the season.

Data on usable standing crops were related to the barren-ground caribou's food habits in winter. Information gathered from Loughrey (33), Banfield (10), Kelsall (27, 28, 29) and Scotter (43) was the basis for high, moderate or low values assigned to shrubs and lichens as winter food. Summer observations of plants grazed during the previous winters and winter observations supplemented this information. Assigned values were not based on nutritive content. The high, moderate, and low values compare only the forage within a group.

To determine the standing crop of arboreal lichens in the northern Saskatchewan study area, the following method was used. Four black spruce and four jack pine trees, each representative of its forest stand, were selected as sample trees. The trees were felled and measured and their trunks divided

into 10-foot sections. Lichens were removed by hand from the trunk and branches of each section. The relative abundance of different species was noted, placed in cotton bags, air-dried at approximately 72° F., and weighed. Five wedge prism readings were taken at each site to estimate the number of trees per acre, and the diameter of trees viewed in each 360° horizontal sweep was measured. Standing crops of arboreal lichens above and below the 10-foot level were calculated in pounds per acre.

Effects of Fire on Soil Properties

Forest fires destroy lichens and other forage, changing the ecological conditions influencing plant growth and development. Changes in floristic composition following fire may result from alterations in soil properties. Chemical and physical changes after fire were therefore investigated at the Saskatchewan study area.

Sampling sites were selected in mature black spruce forests, mature jack pine forests, and on burned-over areas which formerly supported those forests. Sites on burned-over and unburned areas with similarities of slope, topography, drainage and soil parent material were sampled. Four burns were sampled: two in jack pine and two in black spruce stands. The two burns previously covered with jack pine forests were compared with a mature jack pine-black spruce forest with similar slope, topography, and drainage, but slightly different soil. The burned-over areas contained medium textured, pale brown sand; the jack pine-black spruce forest contained medium loamy, grayish sand. Soils in this region are mainly composed of podzols, podzol gleys, and peats.

Physical and chemical data were obtained from the sites in August. Boulders and thin soil mantles sometimes precluded random sampling.

Temperature and erosion were studied. Six temperature readings were taken, with a Weston soil thermometer, at 1- and 3-inch depths at each location. The readings were taken in unshaded areas between 10:30 a.m. and 1:00 p.m. Observations on erosion at each site were made from the ground and from a low-flying aircraft.

A composite sample of 18 soil cores, three from each of six sites per location, was collected from the 0- to 3-inch depth of mineral soil for chemical analyses. Sampling was limited to a 3-inch depth because fire has seldom changed the chemical composition of soils below the upper few inches. The humus layer in burned-over areas had largely been destroyed and could not validly be compared with that in mature forests, so it was not sampled although such layers may be important sources of nutrients, closely related to a site's productivity (19).

The Soil Survey Research Branch of the Canada Department of Agriculture, in cooperation with the Research Council of Alberta, made chemical and pH determinations on the mineral soil cores. Methods of the Soil Survey Research Branch were used to determine exchangeable hydrogen, sodium,

potassium, calcium, magnesium, and total cation exchange capacity. Extractions were as outlined by the Association of Official Agricultural Chemists (7). Calcium, magnesium, sodium, and potassium were determined by use of the Beckman DU flame spectrophotometer with a model 9200 flame attachment and line-operated power supply unit as outlined by Baker (9), and with the modifications suggested by Mathieu and Burtch (36), Mathieu and Carson (37), and Carson, Mathieu, and Scheelar (16). A cleaning solution (17) was used with the spectrophotometer. Total nitrogen was determined by Prince's (40) Kjeldahl method, with mercury as a catalyst.

Available phosphorus was determined by extracting 5 grams of soil with 25 milliliters of 0.03-normal sulfuric acid and 0.03-normal ammonium fluoride. Calorimetric measurements were then taken with a Fisher Model No. A electrophotometer.

Field pH determinations were made with a Beckman Model 180 pocket pH meter by inserting a glass electrode into mineral soil at the desired depth. Composite soil samples, taken from the upper 3 inches of mineral soil, were tested for pH in the Soil Survey Research Branch Laboratory by use of a Beckman Model H2 pH meter. Before pH value was determined, a soil paste, consisting of distilled water and dry sieved soil, was allowed to stand 15 minutes. Field and laboratory pH meters used in this study were compared before the field season to ensure similar results.

Effects of Fire on Range Use by Caribou and Moose

Pellet groups were counted in each 9.6-square-foot circular plot, used for calculating the standing crop of usable forage, to compare use by barren-ground caribou and moose in each forest age class. Six or more barren-ground caribou winter pellets in one plot were recorded as a pellet group. Kelsall (27) regarded six or more pellets as a group because barren-ground caribou generally move while dropping their pellets, leaving a point of concentration and several widely scattered pellets. Each pile of moose summer droppings was considered a group. Pellet groups per stand were then converted to pellet groups per acre.

Results

History and Extent of Forest Fires

Historical review.—Journals of early explorers and their modern day counterparts confirm the prevalence of forest fires throughout the winter range of barren-ground caribou in northern Canada. A review of references concerning fires on the winter range of barren-ground caribou can be found in other publications (42, 44).

Fire control reports.—Government agencies in the District of Mackenzie and the provinces of Alberta, Saskatchewan, and Manitoba provided fire control reports from 1961 through 1964 for the portion of winter range

within their region. Total destruction reported during this period was 5,005,872 acres (45), about 2.7 percent of the winter range, a rather alarming total as the reports do not cover vast portions of the winter range.

Lightning apparently caused 72 percent of the fires (45). Changes in the summer weather pattern in recent decades may have resulted in more lightning strikes or in conditions more suitable to the spread of fire. As would be expected, most fires caused by man occurred near population centers.

Cover maps.—Forest cover maps, prepared from interpretation of recent aerial photographs, show that average destruction by fire in the 1- to 15-, 16- to 30-, 31- to 50-, 51- to 75-, 76- to 120-year age classes was 20,779, 14,080, 15,040, 14,310, and 6,599 acres per year, respectively. Fire destruction in the 1- to 15-year age class was 1.4 times higher than in the 16- to 30-, 31- to 50-, 51- to 75-year age classes, in which the annual rate was almost constant; and 3.1 times higher than in the 76- to 120-year age class. Destruction rate in the 16- to 30-, 31- to 50-, and 51- to 75-year age classes was 2.2 times greater than in the 76- to 120-year age class. These increases coincide with mining activity and white settlement. That some forests may have been burned more than once during the years covered by the five age classes was not considered. Multiple burning would increase the area of young forests and reduce the area of more mature forests.

The historical review and fire control reports reveal that ecological relationships between forest fires and barren-ground caribou have long existed. The cover-map data on forest age classes suggest that destruction has increased in recent years.

Effects of Fire on the Forage Supply

One of the most obvious effects of forest fires is the reduction in the amount of available terrestrial and arboreal forage. Lichens, regarded as the caribou's principal winter food (10, 28, 29), comprise nearly 60 percent of the winter forage, according to data from rumen samples collected in northern Canada (43).

Terrestrial forage.—Average air-dried weight of the usable standing crop ranged from 177 pounds per acre in the 1- to 10-year age class to 1,085 pounds per acre in the over 120-year age class (table 1). Grass and grasslike plants and forbs yielded the highest amounts in the 1- to 10-year age class but gave only a few pounds per acre in subsequent age classes. Shrub production was low in the 1- to 10-year class but was reasonably consistent throughout the remaining age classes. Lichens increased consistently from 3 pounds per acre in the 1- to 10-year age class to 469 pounds per acre in the 51- to 75-year age class. The amount was slightly less in the 76- to 120-year class because caribou made moderate to heavy use of many forest stands. Despite similar use in the over 120-year age class, usable lichens increased to 725 pounds per acre. The high-value group included the so-called "reindeer" lichens, such as *Cladonia alpestris*, *C. mitis*, and *C. rangiferina*. High-value lichens ranged from an average 1 pound per acre in the 1- to 10-year-old class to an average

TABLE 1.—Average standing crop of usable air-dried forage from 126 upland forests in six age classes

Forage type	Forest age classes (years)					
	1-10	11-30	31-50	51-75	76-120	120+
-----Pounds per acre-----						
Grass and grasslike plants	35	8	1	1	3	2
Forbs	68	9	2	3	4	7
Shrubs						
High value	14	124	189	169	248	253
Moderate value	10	8	2	3	4	6
Low value	45	95	83	107	101	92
Subtotal	69	227	274	279	353	351
Lichens						
High value	1	15	147	319	291	560
Moderate value	1	39	76	84	97	129
Low value	1	50	89	66	35	36
Subtotal	3	104	312	469	423	725
Others ¹	2	(²)	0	(²)	(²)	(²)
Total	177	348	589	752	783	1,085

¹Others include club mosses and fungi.

²Trace.

560 pounds per acre in the over 120-year age class. Moderate-value lichens reached their peak abundance in the over 120-year age class, and low-value lichens in the 31- to 50-year age class. Lichen abundance varied within each age class but was generally related to maturity of the forest. Older forests were occasionally less productive than younger forests in the same age class, because tree density, soil type, caribou utilization, and other factors varied.

Lichen destruction is critical because of their slow succession and growth rates and importance as winter forage for barren-ground caribou. Fire is apparently as destructive to the major forage lichens as it is to the mature conifers, when the recovery rate is considered. This study showed that major forage lichens take from 70 to 100 years, and more, to regain their former abundance and composition. The long recovery period is required for the return of biological conditions suitable for lichen growth, for the succession of lichens through a number of seral stages, and because of the slow growth rate. In some sample sites in three of the study areas, the major forage lichens attained an average growth rate ranging from 3 to 5 millimeters per year, depending on the species (41).

TABLE 2.—Standing crop of arboreal lichens in black spruce and jack pine forests in northern Saskatchewan

Forest type	Below 10-foot level	Above 10-foot level	Total
----- Pounds per acre ¹ -----			
Black spruce	605	464	1,069
Jack pine	339	1,490	1,829

¹ Air-dried weight.

Arboreal forage.—In northern Saskatchewan, the standing crop of arboreal lichens within 10 feet of the ground was estimated at 605 pounds per acre in mature black spruce forest and 339 pounds per acre in mature jack pine forest (table 2). Arboreal lichens were less plentiful on many other segments of the winter range. Lichens on fallen trees and lichens dislodged from above the 10-foot level by wind or snow increased the available amount.

Arboreal lichens may be an important food source, particularly when snow is deep or crusted with ice (42), and their destruction by fire must be considered a serious loss of caribou winter forage. *Alectoria*, *Evernia*, and *Usnea* are considered the most important of the arboreal lichens.

Effects of Forest Fires on Soil Properties

Soil temperatures.—Midday summer soil temperatures were higher in burned-over areas than in unshaded, forested areas (table 3). Soil temperatures on the four study plots averaged 10.5° F. higher at 1-inch depths and 9.8° F. higher at 3-inch depths on recent burns than those on unshaded areas in mature forests. Midday temperatures were consistently higher at 1-inch levels than at 3-inch levels. These temperature differences decreased between the burned-over and forested areas as the time since the fire increased. Soil temperatures were higher largely because fire burned away the insulating unincorporated organic matter. In addition, the blackened surface absorbed more heat during the long summer days, although this may have been partly offset by higher radiation at night than in the forested areas.

Bauer (12) in California and Lutz (34) in Alaska have suggested that the addition of charcoal to soil is a factor in its temperature increase. Tryon (52) commented on the heat absorbing capacity of charcoal. Isaac and Hopkins (25) felt that fire increased the capacity of soils to absorb heat, and Kittredge (30) found afternoon March temperatures were more than 20° F. higher at a 1-inch depth on a burned-over area than on a forested area in California. However, Shirley (46) reported no temperature differences on burned and unburned quadrats in a jack pine stand.

TABLE 3.—Midday summer soil temperatures from unshaded areas in burned-over and mature forests in northern Saskatchewan

Description	Temperature at 1-inch depth (average of six readings)	Difference in temperatures	Temperature at 3-inch depth (average of six readings)	Difference in temperatures
----- °F. -----				
5-year-old burn	79.2	12.7 ¹	69.7	14.2 ¹
Mature black spruce	66.5		55.5	
13-year-old burn	82.0	11.8 ¹	64.5	6.5 ¹
Mature black spruce	70.2		58.0	
5-year-old burn	66.3	11.6 ¹	65.0	14.2 ¹
Mature jack pine— black spruce	54.7		50.8	
22-year-old burn	60.7	6.0 ²	55.0	4.2 ²
Mature jack pine— black spruce	54.7		50.8	

¹Significant at 1 percent.

²Significant at 5 percent.

Erosion.—Erosion was not serious after forest fires on the study area. Destruction of plant cover, litter, and organic matter led to no more than light sheet erosion. The low intensity of summer rainstorms, freezing of the soil for about 7 months each year, and rapid colonization by a liverwort, *Marchantia polymorpha*, and such mosses as *Polytrichum piliferum* and *P. juniperinum* can account for the light erosion.

Any loss of soil from the thin mantles would be serious, but gully erosion was noted only twice. In both cases, it was confined to sandy soils in southern regions of the Saskatchewan study area. On two occasions, I witnessed rainstorms on recent burns but noted little surface runoff from rain pelting on exposed soil. Lutz (34) also found surprisingly little erosion after fire in Alaska.

Wind erosion resulting in the formation of small sand dunes was noted on two recent burns in southern sections of the Saskatchewan region but was not considered a serious factor in soil loss.

TABLE 4.—Chemical soil properties on burned-over and unburned forests in northern Saskatchewan

Site description	Exchangeable cations in milliequivalents, <i>per 100 grams</i> of dry soil					Sum of cations	Total exchange capacity	Total nitrogen	Available phosphorus
	H	Na	K	Ca	Mg				
<i>-Parts per million-</i>									
5-year-old burn	4.1	0.1	(¹)	0.4	0.2	4.8	7.3	50	8.5
Mature black spruce	7.0	.1	(¹)	.2	.4	7.7	11.8	100	1.0
13-year-old burn	3.4	.2	(¹)	.2	.1	3.9	4.8	40	26.5
Mature black spruce	3.9	.1	(¹)	.2	.1	4.3	4.9	40	14.5
5-year-old burn	1.9	.1	(¹)	.4	.1	2.5	4.4	50	13.5
Mature jack pine— black spruce	2.4	.2	(¹)	.2	.1	2.9	3.2	30	(¹)
22-year-old burn	1.2	.1	(¹)	.4	.1	1.8	2.9	20	37.0
Mature jack pine— black spruce	2.4	.2	(¹)	.2	.1	2.9	3.2	30	(¹)

¹Trace.

Cation exchange.—Total exchange capacity was lower in three of the four burned-over areas than in mature forests (table 4). Total exchange capacity increased slightly on one 5-year-old burn.

Exchangeable hydrogen was reduced on each burn. Godwin (21) demonstrated reduced hydrogen ion concentration after burning on Vancouver Island, British Columbia.

Exchangeable calcium increased on three sites and remained the same on the fourth. Garren (20) recorded an increase of calcium in his summary of effects of fire on forest soils in the southeastern United States. Burning was accompanied by an exchangeable calcium increase, to several times the original figure (34), in Alaska.

In northern Saskatchewan, little change was noted in exchangeable potassium, magnesium, or sodium. While studying effects of slash burning on soil, Tarrant (50) observed that light burning, defined as the condition in which fire chars but does not remove all organic litter from the surface, increased exchangeable potassium, and had little appreciable effect on cation exchange capacity. But severe burns greatly increased exchangeable potassium and reduced cation exchange capacity. Burning of logging slash in western Oregon and Washington increased soluble or available forms of potassium, calcium, and magnesium (8).

Total nitrogen in mineral soils, as determined by the Kjeldahl method, did not follow any apparent trend. It increased on one burn, was reduced on two, and remained the same on the fourth. A review of literature also revealed contradictory results. Barnette and Hester (11), Isaac and Hopkins (25), and Austin and Baisinger (8) reported decreases in nitrogen, but Heyward and Barnette (24) and Garren (20) reported increases. Tarrant (50) reported light slash fires stimulated nitrification, and severe fires reduced nitrogen content. Lutz (34) reported forest fires caused an immediate reduction in total nitrogen but an increase in available nitrogen.

Available phosphorus was present in greater amounts on the four burns than in the adjacent unburned forests. Thorne and Peterson (51) believed that the absence of large amounts of calcium increased the availability of phosphorus. After fire in Alaska, the available phosphorus increased in upper mineral layers (34). Austin and Baisinger (8) found that phosphorus increased more than twofold on burned-over plots in Washington and Oregon.

Soil pH.—Under field conditions, soil pH values were higher in all burned-over areas than in unburned forests (table 5). Acidity decreased at 1-inch and

TABLE 5.—Soil pH in burned-over and unburned soils in northern Saskatchewan

Site description	Laboratory sample, 0- to 3-inch depth	Field sample, 1-inch depth (median of six readings)	Range	Field sample, 3-inch depth (median of six readings)	Range
5-year-old burn	4.7	6.45	5.2-6.8	6.15	5.7-6.8
Mature black spruce	4.4	5.0	4.2-6.3	5.6	4.5-6.8
13-year-old burn	4.6	5.4	5.2-6.2	5.6	5.2-6.1
Mature black spruce	4.5	5.2	4.7-5.2	5.4	5.0-5.5
5-year-old burn	4.7	5.5	5.4-6.4	5.3	5.2-6.2
Mature jack pine—black spruce	4.0	5.1	5.0-5.3	5.2	5.2-5.5
22-year-old burn	5.2	5.9	5.4-6.2	5.8	5.2-5.9
Mature jack pine—black spruce	4.0	5.1	5.0-5.3	5.2	5.2-5.5

3-inch depths in the burned-over soils. Although they had a lower pH than field samples, laboratory samples showed the same trend of higher soil pH on recent burns. Destruction of unincorporated organic material and addition of alkalis from wood ash probably caused lower acidity.

Many workers have reported lower soil acidity after fire (35, 11, 20, 34, 13). In Sweden, pH values were higher for about 25 years on burned-over areas than on adjacent unburned areas (53). The severity of the burn, however, may influence the number of years that the higher pH values will be retained.

In previous studies, the effects of fire on soil properties have varied widely with differences in soil type, climate, vegetation, and severity of the burn. Ahlgren and Ahlgren (3) reviewed much of the literature on the effects of fire on soil properties. Lutz's (34) investigation in Alaska is the only other North American study made at a latitude comparable to northern Saskatchewan and in similar forest types I know of. From his study, Lutz (34, p. 78) concluded in part:

No possible justification for uncontrolled wildfires can be found in the realm of soil science. Such fires can never be justified or even excused on the basis of beneficial effects on the soil, despite the fact that fires may have favorable effects on certain properties.

The effects of fire on forest soils are favorable to certain soil properties and unfavorable to others. To determine whether the deleterious effects exceed the beneficial effects in northern forests, studies of lichen and vascular plant ecology must be conducted.

Higher surface soil temperature on burned-over areas may be ecologically favorable for the germination, emergence, and growth of certain plants. Dubetz, Russell, and Anderson (18) found that higher soil temperatures generally increased the rate and percentage of emergence of native and cultivated herbaceous species. How higher soil temperatures influence lichen regeneration is unknown. The boreal *Cladinae* are moderately heat resistant (4), but the higher summer soil temperatures and increased wind action caused by the removal of vegetative cover may increase water evaporation, which could result in desiccation of lichen stands. Lichens are strongly influenced by the abundance or lack of moisture (48). They can endure desiccation, but their metabolism, respiration, and assimilation are impaired by insufficient water.

Soil pH is broadly correlated with the distribution of some plant species. Wilde (54) gave a pH range of 4.7 to 6.5 as optimum for white spruce growth, although other conditions can drastically modify the effect of soil reaction. Many plants on the winter range, such as Labrador tea, are considered acidophilous. The pH of the substrate is generally believed to be an ecological factor of prime importance in the distribution of lichens. Most important forage lichens are found in habitats with pH values ranging between 4.5 and 5.5 (4).

Little is known about the effect on most plants of the boreal forests of increased or reduced nutrient supplies. The general increase of nutrients resulting from ash may stimulate growth of some species and inhibit growth of others. Ahlgren (2) found that oats and sunflowers grown in soil from lightly burned-over areas increased in vigor and size compared with plants grown in soils from unburned areas, but plants grown in soil collected after a severe summer fire were no larger than those grown in soils from unburned areas.

Ahlgren (1) suggested high concentrations of salts released from ash may cause plasmolysis of root hairs and young roots and kill or retard growth of seedlings. Heikinheimo (23) found that ash damaged spruce seedlings more easily than pine seedlings.

The nutrient requirements and tolerance levels of lichens have received little attention, but lichens may have specific mineral requirements (22). "Reindeer" lichens obtained most of their water and nutrients from rain and from the atmosphere (4), but soil quality was important during early lichen growth. According to Ahti, most species avoid calcareous soils and prefer the acid humus of podzols during germination. Addition of wood ash to lichen stands in Russia proved harmful to lichens (6).

Infrequent fire may not be disastrous to the fertility of mineral soils in the Saskatchewan study area. Higher postfire soil temperatures and reduced soil acidity may stimulate or inhibit plant germination and growth, and studies are needed to determine which are the plants affected. Many of the barren-ground caribou's preferred food species are associated with sites having low pH. The effects of soil temperatures on the emergence of such plants as lichens require further investigation.

Range Use by Caribou and Moose

Fire in an upland spruce forest changes the community's cover of trees, shrubs, bryophytes, and lichens into a tangle of fallen snags, exposed soil and, later, into a cover of fireweed, grass, and shrub. This alteration in kind and quality of plant cover is an indirect but important effect, as it subsequently modifies wildlife populations.

TABLE 6.—Average number of caribou and moose pellet groups per acre in forest stands by age classes

Kind of pellet groups	Age classes (years)					
	1-10	11-30	31-50	51-75	76-120	120+
Caribou	18	139	149	498	633	722
Moose	18	49	26	13	13	3

Table 6 shows the densities per acre of barren-ground caribou and moose pellet groups for the various forest age classes. Sampling yielded an estimated 722 caribou pellet groups per acre in forests over 120 years old, and only 18 per acre in those 1 to 10 years old. There were 49 moose pellet groups per acre in the 11- to 30-year age class and only three per acre in the over 120-year age class. Moose apparently prefer habitats under 50 years old, and barren-ground caribou those over 50 years old.

In aerial observations, during the winter, of northern Saskatchewan and the southern Mackenzie District, it was easy to see feeding craters dug in the snow by barren-ground caribou. The frequency and distribution of these feeding craters agreed with the pellet-group counts within various forest age classes. The craters were largely confined to mature forests. A few trails and feeding craters in recent burns were made by animals crossing from one mature forest to another.

Forest fires improved ranges for moose in some areas of North America, such as the Kenai Peninsula of Alaska, and resulted in higher moose populations (31, 32, 49). But a large moose population was not evident in the study areas. The postfire vegetation on upland sites contained only small amounts of some browse plants preferred by moose, such as willows (*Salix* spp.). White birch, a good moose food, was abundant in many of the younger forest stands which had been disturbed by fire.

Discussion

The results of this study apply only to upland lichen forests, considered by the writer to be the most susceptible to long-term destruction by fire and the most important single source of winter forage for barren-ground caribou. The research was oriented to a single species and did not consider the advantages or disadvantages to other animals of the region, except for moose. The study does not imply that fires are detrimental to all caribou habitat.

In the southern limits of the barren-ground caribou's winter range, fires sometimes destroy thick carpets of bryophytes in upland forests thereby making them more productive for lichens and other forage plants. But this advantage is more important in the closed forest stands. Fires also improve certain muskeg areas by destroying *Sphagnum* spp. and other bryophytes which are replaced with forage preferred by caribou.

Ahti and Hepburn (5) suggested that lichen supply could be increased for caribou in the northern boreal lichen belt of Ontario by burning the *Sphagnum fuscum* peatlands, treeless bogs, or wooded muskegs; and further south by burning the black spruce-feather moss forests and black spruce muskegs. In addition, they recommended removing black spruce seedlings and thinning jack pine stands to keep the woodlands from reverting to a black spruce-feather moss community. The upland lichen woodlands within

the barren-ground caribou's winter range are generally sparsely treed and need no thinning to maintain a condition favorable to lichen stands. Some of my research has suggested that fires may beneficially affect nutrient cycling, increase summer soil temperatures, remove excessive humus layers, and increase moose browse in many areas (42, 44). Kayll (26) summarized other beneficial influences of fire in the boreal forest region of Canada, but some of his comments may not apply to the taiga of that region.

Skoog (47) stated that range losses from fires in Alaska were greatly mitigated because caribou did not depend on lichens in spruce forests for forage, as they could utilize forages in other communities, such as tundra and alpine meadows. He concluded that fires had little influence on fluctuations in caribou numbers in Alaska. But there is a marked contrast between much of the caribou's winter range in northern Canada and that in Alaska. Burning of winter range in the relatively flat taiga of northern Canada might send caribou many miles in search of forage; in Alaska, it might send caribou only a short distance up the mountainside into the alpine region. Despite his suggestion that lowlands are not used commonly by caribou, Skoog indicated that in some areas, such as the Kuskokwim Mountains where alpine areas are limited, burned sections may have inhibited a buildup of caribou numbers.

Referring to the caribou winter range in interior Alaska, Leopold and Darling (31) wrote "... fire had played so dominant a part in destroying the lichen range that we feel quite safe in attaching to that one factor the major blame for caribou decrease." No attempt will be made to explain the contrasting views of Skoog and Leopold and Darling regarding the role of fire on those ranges. Perhaps such contrasting views reflect the need for detailed research on the ecology of fire in northern environments, with a realization that data from one region should not be applied to all northern areas.

Referring to Newfoundland caribou, Bergerud (14a, p. 39) concluded that:

... forest fires in the past have increased the extent of winter range by altering closed-canopy forests to lichen woodlands or shrub-barrens, and prostrate sub-alpine spruce-fir thickets to lichen-shrub barrens.

Bergerud (14, p. 941) also stated that:

For decades wildlife biologists have thought that caribou require mature undisturbed lichen stands and that range destruction by fire and overgrazing was the antithesis of caribou abundance. Yet no proponent of this view has documented reduced reproduction or increased mortality among lichen-deprived free-ranging caribou. A significant correlation between lichen abundance and caribou distribution is not sufficient evidence that lichen abundance also limits caribou numbers.

Although there is little evidence to show a direct relationship between range destruction and population declines in northern Canada, most of the research started after the population was near its lowest level. It is therefore impossible to obtain the evidence required by Bergerud. But studies do show that fire can reduce the carrying capacity of lichen winter ranges. Climax plant communities provide a large part of the food caribou prefer, and lichens generally constitute a large portion of the winter diet, whether or not they are necessary to the animal's survival. Ecological succession after fire may well be more rapid in Newfoundland for it is further south than the barren-ground caribou's winter range and has a maritime climate. In addition, Bergerud's (14a) comments on forest fires apply to closed canopy forests and not the more open coniferous forests generally used by barren-ground caribou.

Fire has decreased the potential carrying capacity of the barren-ground caribou's upland winter range in the taiga and increased that of the moose range, but the potential meat yields are not necessarily the same. Barren-ground caribou spend approximately half the year in the tundra, which might otherwise go unutilized, and half the year in the taiga. Moose are more solitary than barren-ground caribou and depend on an appropriate mixture of habitat within a localized area. The barren-ground caribou is unquestionably the only native ungulate in the region adapted to using the high energy, low protein lichen components of the upland taiga forest. This does not imply that lichens are required but only that caribou are adapted to utilizing them.

Symptoms of range deficiencies or starvation, such as poor physical condition, emaciation, lack of fat, severe outbreaks of disease, and parasitism, have not been widespread, although some possible symptoms of nutritional deficiencies have been identified. McEwan (38) reported that only 68.8 percent of the females over 3 years old were pregnant during the severe winter of 1961-62. Calf mortality has been high during certain years (29). Bergerud (14, p. 941) questioned whether early calf mortality during certain years was "... an evolutionary imperative ... or an artifact of range destruction and inadequate maternal nutrition, hence, low viability of calves at birth?"

Forest fires also have other indirect effects. For example, Banfield (10) observed that recent burns, like topographical obstructions, deflect barren-ground caribou migrations; Kelsall (27) and Scotter (44) have noted that barren-ground caribou tend to avoid areas in the young successional stages and are consistently more abundant in open mature spruce or jack pine forests. Snow conditions, low forage production, and windfallen trees make recent burns unattractive to caribou.

Conclusions

Although fire damaged winter range of barren-ground caribou before the white man came to North America, its destruction rate has increased with

the growth of settlement and exploitation. In addition, changes in the summer weather pattern may have contributed to the loss of potential habitat. Fires adversely affect the standing crop of terrestrial and arboreal forage, apparently affecting lichens more seriously than other forage plants because their reestablishment is delayed and their growth rates are slow.

Fire appears to reduce the winter range for barren-ground caribou and increase it for moose on upland forests studied. The biomass of caribou per acre of mature forest appears higher than that of moose on early subclimax forests on upland sites. Thus, for meat production, the upland lichen forests may be best suited to barren-ground caribou.

Research data from northern Canada are insufficient to determine the extent to which forest fires have directly influenced the recent decline of the barren-ground caribou population. But forest fires so affect the standing crop of forage, plant succession, and animal use that they may have been among the principal causes of the decline. The present winter range, with its vast fire-destroyed areas, will not permit an increase in numbers to the level of 60 or 70 years ago. Reduced potential carrying capacity does not appear to be the factor limiting the caribou population to the present low levels yet may have reduced it to the point at which men, wolves, and other factors could keep the numbers low.

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Natural regeneration of interior Alaska forests - seed, seedbed, and vegetative reproduction considerations

Abstract

The forests of interior Alaska are a complex mosaic of stands which are, to a significant degree, related to the fire history of this area. Following fire the major interior forest tree species—white spruce, black spruce, paper birch, quaking aspen, and balsam poplar—can regenerate from seed and/or by vegetative means. Various aspects of seed production (including seedbed considerations) and vegetative reproduction, as they may relate to burn reforestation, are discussed.

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Introduction

The forests of interior Alaska are a complex mosaic of stands which are, to a significant degree, related to the fire history of this area. The five major interior tree species, white spruce (*Picea glauca* (Moench) Voss), black spruce (*P. mariana* (Mill.) B.S.P.), paper birch (*Betula papyrifera* Marsh.), quaking aspen (*Populus tremuloides* Michx.), and balsam poplar (*P. balsamifera* L.) are not fire resistant. However, as shown by Lutz (16), hardwood stands and trees may be damaged less than spruce by fire because of the tree and forest floor characteristics peculiar to each species. Fire also consumes tree seed lying dormant on the forest floor. Thus, following a forest fire, the burned area is totally or partially devoid of living trees, and any seed which was on the ground and might have been of potential value in regenerating the site has been consumed by fire. Therefore, complete or partial natural reforestation of the site is requisite to maintaining forests and trees as a dominant form of vegetation.

Natural reforestation can result from seed or from vegetative reproduction. All interior Alaska species are capable of regenerating by means of seed disseminated from trees (living or dead) on the burned area or in adjacent, unburned stands. Vegetative reproduction of burns is probably limited to aspen, balsam poplar, and birch; obviously, the species must have been a component of the prefire forest in order to reforest the area by this means. This paper considers the initial phases of these two processes—that is, seed

supply, seedbed requirements, and vegetative regeneration variables. The discussion is limited to these variables because they are basic to reforestation and because entirely different factors must be considered in the next steps in regeneration, i.e., seed germination and seedling growth and establishment.

Alaska-derived data are used where available; and, in this sense, this paper updates and supplements Lutz (16). Where Alaska data are unavailable, other information is used. Because of the varying intensity of research on the different variables for each species, the quantity and scope of data vary considerably among species. Most of the data presented are derived from studies conducted in unburned commercial forest areas. However, the variables to be considered are the most basic aspects of reforestation, and the data presented should realistically characterize these factors as they relate to reforestation of burns.

Tree Age and Seed Production

The relationship between tree age and seed production becomes important when areas are subject to repeated fires and perhaps where the advance of tree reproduction into large burned areas is of concern. Those species which are able to produce seed in significant quantities relatively early in their life cycle have an advantage over species which produce seed later. Age at which first abundant and optimum seed production occurs may vary between species. The age-seed production relationship may be altered significantly by biological, climatic, and edaphic variables.

White spruce.—Cones have been observed on trees as young as 10 years, and excellent seed crops have been observed in 20-year-old forest plantations. However, it would appear that quantity seed production in natural stands probably does not begin until age 40 years or older. The delay in natural stands is probably more the result of variation in stand density and competition than of inherent differences between trees in plantations and natural stands. In Alaska, good cone crops have been observed on trees from 45 to 170 years old or older (33).¹

Black spruce.—Small quantities of seed have been observed on 10- to 15-year-old trees in natural stands. Most stands over 25 years of age bear seed regularly. Optimum age for seed production is between 50 and 150 years, but commercial seed crops occur in black spruce 250 years old (10, 30). Individual trees in Alaska from 24 to 194 years old have been observed to produce good cone crops (500 or more new cones produced per tree in 1968).²

Paper birch.—Trees of this species begin bearing seed at about age 15 years; optimum bearing age is from 40 to 70 years (13). Alaska paper birch

¹This literature review covers many aspects of white spruce regeneration and, rather than cite numerous papers, the literature review is cited.

²Unpublished data on file at the Forestry Sciences Laboratory, Institute of Northern Forestry, Pacific Northwest Forest and Range Experiment Station, College, Alaska.

stands ranging from about 45 to 100 years old have been observed to produce large quantities of seed (see footnote 2).

Quaking aspen.—The minimum commercial seed-bearing age is 20 years, and the optimum is 50 to 70 years (26).

Balsam poplar.—No data were found on minimum or optimum seed-bearing age for this species.

Summary.—These data indicate that white spruce may be the species which begins abundant seed production latest in its life cycle. Optimum seed production appears to begin at 40 to 50 years for the species for which data are available. White and black spruce continue to produce seed up to at least 200 years of age. The short-lived hardwoods may not produce large quantities of seed much beyond an age of 100-120 years.

Ripening and Dispersal of Seed

Prompt regeneration of a burn is desirable, particularly when commercial forest areas are burned and where unstable soil conditions (e.g., permafrost) occur. The most efficient means of reforestation would result if seeds on the trees at the time of the fire were available. It seems doubtful that seed would ripen to any degree following death of the tree by fire; rather, it seems more probable that seed-bearing organs would desiccate and, depending on their maturity, either disperse or retain the contained seed. Thus, in order to have the currently formed seed crop of value, it would probably have to be ripe at the time of burning.

Seed on trees that have been killed by fire will be important only if not burned or destroyed by heat generated by the fire. In order to affect seed-bearing organs, the fire will have to burn in the crown of the tree or close enough to it to generate high temperatures. Fires in hardwood stands may be less intense than in spruce owing to the nature of the organic matter and a branchless nature of the tree bole. Spruce stands (black spruce of all ages and younger white spruce) are very susceptible to crown fires and possible burning of the cones because of vertical continuity of branches. However, it has been observed that clusters of black spruce cones contain sound viable seed after burning (10, 32). In general, then, it would appear that there could be trees of all species within burns or there could be seed-bearing organs on trees that still have potentially valuable seed after fire.

White spruce.—Although small amounts of seed may be ripe (i.e., will produce seedlings) in late July, the majority of the seed does not ripen until the end of the first or second week in August. Seed dispersal has been observed as early as August 18 (a very warm, dry summer) and as late as September 5 (an abnormally cool, wet summer). Seventy-five to 90 percent of the seed crop is dispersed within 3-4 months of initial cone opening (34).

Black spruce.—Seed ripens in early September in southern black spruce stands. Seed dispersal is more gradual than in white spruce (10). Lebaron (15) reported that, on the average, 9 percent of annual dispersal occurred in

August, 19 percent in September, 38 percent from October to April, 13 percent in May, 14 percent in June, and 7 percent in July.

Paper birch.—Ripening occurs in late summer, from early August to mid-September (13). Seed dispersal in southern parts of the species range has been observed as early as July 4; however, peak dispersal normally occurs between August and October. More than 90 percent of the seed crop is dispersed by December (6). In Alaska, seedfall has been observed as early as mid-July (see footnote 2). Large quantities have also been observed to be dispersed after leaf fall. Reports of dispersal in early July in Alaska and elsewhere indicate that seed ripening may occur before August.

Quaking aspen.—Seed dispersal occurs within a few days of ripening (26). Dispersal has been observed in mid to late June near Fairbanks (see footnote 2). Graham et al. (8) report dispersal of aspen seed in late May in Michigan.

Balsam poplar.—Seed-bearing capsules mature during May or June, when leaves are about two-thirds expanded; dispersal occurs shortly after (25). Dispersal has been observed in early June near Fairbanks (see footnote 2).

Summary.—These data in conjunction with the following information on fire occurrence (4) give some insight into the potential value of seeds on trees in reforesting a burn.

Month	Cumulative percent of fires
March	1
April	3
May	22
June	61
July	86
August	94
September	98
October	100

Somewhat more than 86 percent of all fires occur before white spruce seed maturity. Thus, it seems that little, if any, of the current seed crop of fire-killed trees would be of value in reforestation. Seed dispersal from adjacent unburned stands begins after most fires occur and could be used efficiently.

Some black spruce seeds are available at all times because of semi-serotinous nature of the cones. However, 90 percent of all fires probably occur before the new seed crop matures. Thus, seed on the trees in older cones is probably far more important than seed developing at the time of the fire.

Paper birch is generally similar to white spruce except that reports of July dispersal indicate that seed may mature by July of some years and may be of value for regenerating burns occurring from mid-July to October. This would also mean that any seed dispersed in July might be destroyed by the fire.

The report of ripening and dispersal of aspen and poplar seed in June

indicates that seeds of these species are probably available to regenerate burns occurring in June and July. However, because of the limited life of the seed (see below), these species are restricted in a different sense.

Quantity, Quality, and Dispersal Distance of Seed

The size and quality of seed crops determine the amount of seed potentially available for regeneration. Seed quantity and quality, in conjunction with seed dispersal distances, indicate the ability of the species to seed large burned areas. Seeds of interior Alaska species are primarily disseminated by wind. Other means of dissemination are over snow, in water, or by animals. The importance of these secondary means of movement has not been quantified and may be of significant importance in regeneration of some burned areas.

White spruce.—Seed production by white spruce in interior Alaska has been observed to vary annually from near zero to 16 million seeds per acre. Seed quality (percent of total crop potentially viable) has varied between 6 and 70 percent (average 45 percent). The higher percentages usually occur during the better seed years. Estimated seed production by individual trees in 1968 was between 54,000 and 64,000 seeds per tree (35,000-39,000 filled). Seed production by individual cones has varied between six and 62 seeds in Alaska (33, 34).

Maximum distance from the seed source for the spread of adequate quantities of seed is about 150-200 feet (33). Limited data for Alaska indicate that 50 and 90 percent of the seed dispersed from the top of a 60-foot-tall tree landed 90 and 210 feet, respectively, from the base of the leeward side of the tree (windspeed averaged 6 m.p.h.); only 2 percent traveled more than 300 feet. Sixty-five percent of this seed was in the air 40 or less seconds and 98 percent less than 80 seconds (see footnote 2).

Black spruce.—Because of the semiserotinous character of black spruce cones, quantity and quality of seed can be considered from the current cone crop as well as from previous cone crops. Lebaron (15) found an average of about 180,000 viable seeds per acre in new cones and about 137,000 in 1-year-old cones in northern Minnesota swamp stands. About 2 percent of the viable seed remained in 4-year-old cones, and some viable seed was still retained in 15-year-old cones (10). Wilton (32) reported that, during a 60-day period after a fire on August 25, about 1.5 million black spruce seeds (40-percent viability) were dispersed. Salvage operations caused approximately another 1 million seeds to be dispersed (20-percent viability). No data are available on seed quantity in Alaska; however, the quantity of seed produced by other species (e.g., white spruce and paper birch) appears to be equal to or greater than production estimates elsewhere. Germination percentages for seed from 85 trees in interior Alaska averaged 47 (range, 7 to 86 percent) (see footnote 2).

Heinselman (10) reported 300,000 seeds per acre within a black spruce stand, 19,000 at 100 feet from the stand, and virtually none beyond 300 feet. He concluded that effective dispersal is two or three tree heights from the parent tree. This would indicate very limited distance of dispersal from interior Alaska stands or individual trees because of the short trees.

Paper birch.—Birch seed production in four undisturbed Alaska stands for the period 1958-63 varied between 2.2 and 300 million seeds per acre. Average annual production for all stands during this period was 92 million seeds per acre. The quality of seed varied between about 1 and 42 percent (average 17 percent). The quantity of filled seed varied between 176,000 and 114 million seeds per acre (see footnote 2). Percentages of filled seed were less than those reported for this species in New England and other areas (29, 6).

Marquis (20) reported that quantity of birch seed reaching the ground two tree heights from the bordering seed trees was only about 15 percent of that within the stand. Based on Alaska data and above information, the amount of seed reaching the ground at two tree heights from the seed source would vary between about 26,000 and 17 million (average 14 million) seeds per acre. Considerable quantities of seed may be carried farther in strong winds.

Quaking aspen.—Lutz (16) cited a northern European study that estimated aspen stand seed production at between 162 and 202.4 million seeds per acre. It was also reported that during a good seed year individual trees may produce as many as 54 million seeds. The viability of fresh fertile seed is high but normally of short duration. Barnes (personal communication)³ has found seed germination as high as 98 percent. Under favorable natural conditions, seeds are believed to remain viable for a period of only 2 to 3 weeks after maturity (26). Observations reported by Graham et al. (8) indicated that seed viability may be of a longer duration.

The long, silky hairs attached to aspen seed allow dispersal over long distances (26). No detailed information is available.

Balsam poplar.—Lutz (16) and Roe (25) reported that this species produces seed annually and in large quantities. No quantitative data were found concerning seed quantity and quality in this species, but it may be similar to that of aspen. Seed dispersal characteristics are also probably similar to those of aspen.

Summary.—These data indicate that the three hardwood species produce the greatest quantity of potentially viable seed, as well as having the greatest potential dispersal distances. The two spruces may have equal or higher percentages of filled seed but cannot produce seed in the tremendous quantities that the hardwoods are capable of producing.

The data reported for all aspects of seed production were collected in commercial stands at lower elevation for all species. In these areas, growing conditions are generally adequate for growth in all years.

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However, at higher latitudes and elevations, this may not be the case. In 1970, white spruce at 2,000 feet and higher in the Alaska Range produced cones but, in some areas, did not appear to produce viable seed. Observations at several times during the growing season indicated that cone and seed development was at least 2 weeks to a month behind similar development in the Fairbanks area (see footnote 2). Latitudinal and elevational effects on cone and seed production are well established for Norway spruce (*Picea abies* (L.) Karst.) in Europe (33). The point to be made is that seed quality may decrease significantly and seed crops become less frequent with increasing latitude and elevation of stands, thus decreasing regeneration potential following fire on these sites.

Periodicity of Seed Years

Seed crop periodicity becomes important in determining how long regeneration may be delayed because of poor seed years. Depending on the species and the quantity of seed produced annually, this variable can be very important for some species.

White spruce.—Excellent seed crops are known to have occurred in 1958 and 1970. Lutz (16) also reported observation of a good seed crop in 1952. Between 1958 and 1970, two relatively good cone crops were observed as well as three extremely poor years (see footnote 2 and Zasada and Viereck (34)).

It is interesting to note that the excellent 1958 and 1970 seed crops occurred in years immediately after two of the worst fire years on record (4). This substantiates reported correlations between excellent seed crops and warm, dry weather during the preceding year at the time of bud differentiation (33).

Black spruce.—Heavy seed crops occur about once every 4 years and total crop failures are infrequent in southern stands (10). Because good white spruce seed crops appear to be separated by longer periods in Alaska than elsewhere, it seems that this may also be true for black spruce. This variable assumes less importance in black spruce because significant quantities of viable seed are almost always present in the semiserotinous cones.

Paper birch.—Relatively large quantities of birch seed appear to be produced annually in interior Alaska with excellent crops occurring every 2 to 4 years (see footnote 2).

Quaking aspen.—Good seed crops are produced every 4 or 5 years with light crops in intervening years (26).

Balsam poplar.—This species is believed to produce seed in large quantities nearly every year (25).

Summary.—Birch, aspen, and poplar produce large seed crops at the most frequent intervals. Good black spruce crops may occur more frequently than those of white spruce but do not appear to be as large as those produced by white spruce.

Viable Seed to Seedling Ratio

The effectiveness of a seed crop will be determined in part by the number of viable seeds required to produce an established seedling. This is a difficult generalization to make because of the many variables which either directly or indirectly affect the germination and establishment of seedlings. However, data of this nature are potentially useful for estimating the quantities of seed needed for forest establishment.

White spruce.—Between six and 12 viable seeds are required to produce one established seedling on mineral soil seedbeds. (Seeds used in the various studies reporting these data were generally treated to afford some degree of protection against bird and rodent consumption.) On litter seedbeds, 800 to 1,000 seeds were required per seedling (33). Exploratory direct seeding on mineral soil in Alaska with untreated seed indicated that between 12 and 24 seeds were required for each one-growing-season-old seedling produced (see footnote 2). With significant mortality of these seedlings assured, it can probably be expected that at least twice as many seeds may be required per established seedling. Observations on undisturbed organic matter indicate that seedlings are rare and establishment rarely, if ever, occurs on such seedbeds.

Black spruce.—Johnston (14) reported two established seedlings per 100 seeds (95-percent viability) on undisturbed litter seedbeds; for compacted, scalped, and burned seedspots corresponding values were 18, 29, and 22, respectively. Lebarron (15) reported that 31 percent of seed sown produced 1-year-old seedlings on mineral soil, 6 percent on scarified and shaded duff, 4 percent on burned duff, and 1 percent on undisturbed duff. Richardson (24) reported that sowing rates of 100,000 and 200,000 seeds (85 percent viable) per acre produced adequate stocking and numbers of 5-year-old seedlings (80 percent and 3,600 seedlings per acre at 100,000 rate and 84 percent and 5,480 seedlings at 200,000 rate).

Paper birch.—Marquis et al. (21) reported that, depending on seedbed and climatic conditions, between 20 and 400 birch seeds are required to produce a single 1-year-old seedling. With additional mortality assured, this is probably a conservative estimate.

Quaking aspen.—Graham et al. (8) reported that, although seedlings may germinate in great abundance, very few survive. Barnes (2) reported that plots containing 18 to 450 newly germinated seedlings did not contain any living seedlings after 2 years. Although it is generally believed that reproduction of aspen stands occurs most commonly by vegetative means, it is significant to note that Lutz (16), Graham et al. (8), and Barnes (2) all report numerous aspen seedlings on recently burned sites in Alaska, Michigan, and northern Idaho.

Balsam poplar.—Seed of this species (as with aspen) does not exhibit dormancy and appears to germinate immediately after dispersal; if seedbed conditions are unfavorable, the seed dies. Lutz (16) reported balsam poplar

seedlings were abundant wherever mineral soil has been exposed and a seed source is present. This species commonly regenerates by seed on river bottom sites, but seedbed conditions on these sites are probably more desirable than on burned areas.

Summary.—There is little doubt that the spruces, in general, have a significantly lower viable seed to seedling ratio than hardwoods. However, when considered in conjunction with the total number of viable seeds produced, birch maintains a significant advantage over spruce in the number of seedlings that could potentially become established per average seed crop. Aspen and poplar regenerate by seed under only the most ideal conditions and, even then, the possibility of seedlings surviving is reportedly quite small. As mentioned, however, the reports of seedling *Populus* stands in burned areas may make this means of reproduction more important than it is usually believed to be.

Caution must be exercised in general acceptance of these data for several reasons. Mineral soil conditions in some burned areas in Alaska may be very harsh and significantly increase these ratios; for example, the extremely wet and relatively colder conditions which may occur on some sites (ridgetops and areas of coarse textured soils and permafrost). In addition, the organic matter data, with the exception of black spruce, were derived on relatively thin organic layers (2-3 inches or less). Black spruce data were derived on deep organic soils which generally have fairly good water contents. Organic layers in Alaska before burning may be up to 10 inches or more in thickness and if not consumed in burning will increase these ratios or may prevent establishment in some cases.

Seedbed Requirements

Requirements which a seedbed must provide for germination and seedling establishment are adequate moisture, sublethal seedbed temperatures, and reduced competition. Whether a seedbed meets these requirements depends on a number of interrelated variables among which are seedbed material, aspect of seedbed, shading of seedbed, and seedbed water content (table 1). Literature from other areas concerning optimum seedbeds for species occurring in Alaska and general observation by the author and others indicate that, under Alaska conditions, mineral soil comes closest to optimizing these site variables, e.g., white spruce (16, 33), black spruce (15, 10), paper birch (21), quaking aspen (26, 2), and balsam poplar (16, 25). However, organic materials (e.g., humus, rotten wood) or mixed mineral soil-organic matter supplied with adequate water throughout the growing season are excellent seedbeds and may be even more desirable than mineral soil for rapid growth and establishment of seedlings. It appears, though, that organic layers in Alaska are not provided with enough water to make this material a good seedbed.

The amount of mineral soil exposed by prescribed burning or wildfires will vary with time and place of burn. Lutz (16) reported that mineral soil

TABLE 1.—Seed, seedbed, and vegetative reproduction variables for white spruce,

Variable	White spruce	Black spruce	Paper birch
Seed production-tree age relationship in natural stands:			
First abundant production	About 40 yrs.	24 yrs.	15 yrs.*
Period of optimum production	40 to 170 or more yrs.	24-194 or more yrs.	45-100 yrs.
Seed ripening	End of 1st to 2d week in Aug.	Early Sept.*	Maybe as early as July, but most commonly Aug. to Sept.*
Dispersal:			
Initial	Mid-Aug. to early Sept.	Sept.*	July to Sept.*
Duration	75-90 percent dispersed by Dec.	Throughout year*	90 percent by Dec.*
Seed quantity (seeds per acre)	0 to 16 million	300,000 to 2 million*	2.2 to 300 million
Seed quality (percent of total crop)	6-70 percent (average, 45 percent)	7-86 percent (average, 47 percent)	1-42 percent (average, 17 percent)
Dispersal distance	150-200 ft. (2 tree heights)	2-3 tree heights*	At least 2 to 3 tree heights*
Periodicity of maximum seed crops	10-12 yrs.	Every 4-6 yrs.*	2-4 yrs.
Viable seed-seedling ratio:			
Mineral soil	At least 12 to 24	3*	20-400*
Organic matter ¹	800 to 1,000*	100*	400+*
Seedbed requirements (i.e., believed most optimal under Alaska conditions)	Mineral soil	Mineral soil	Mineral soil*
Vegetative reproduction:			
Type	Adventitious shoots*	Layering, adventitious shoots	Sprouting of dormant buds
Capacity	Rare*	Common under disturbed conditions but of doubtful importance in burns*	Common under some conditions*

*Variables for which no Alaska data are available.

¹ Thickness of organic layers generally less than 2-3 inches except in black spruce where the data were derived from studies on organic soils.

black spruce, paper birch, quaking aspen, and balsam poplar in interior Alaska

Quaking aspen	Balsam poplar	Summary and ranking by species
20 yrs.*	*	Earliest to latest Birch > aspen \geq poplar > black spruce > white spruce
50-70 yrs.*	*	Longest to shortest optimum period Black spruce \geq white spruce > birch \geq aspen \geq poplar
June*	May or June*	Earliest to latest Poplar > aspen > birch \geq white spruce > black spruce
June*	Early June*	Earliest Poplar > aspen > birch \geq white spruce > black spruce
June-July*	June*	Latest Black spruce > white spruce \geq birch > aspen \geq poplar
Up to 200 million*	*	Longest Aspen \geq poplar \geq birch > white spruce > black spruce
Maybe very high (98 percent) viability of short duration under natural conditions*	*	Shortest Birch \geq aspen \geq poplar > white spruce > black spruce
Long distance*	*	Farthest Aspen \geq poplar > birch \geq white spruce > black spruce
4-5 yrs.*	Large quantities every year*	Shortest Most frequent Aspen \geq poplar \geq birch > black spruce > white spruce
Probably many thousands*	Approaching many thousands*	Least White spruce \geq black spruce > birch > aspen \geq poplar
Impossible*	Impossible*	Most White spruce \geq black spruce > birch > aspen \geq poplar
Mineral soil*	Mineral soil*	
Root suckers	Root suckers	
Very common in fire-killed aspen stands	Common*	Aspen \geq poplar > birch > black spruce > white spruce

exposure averaged 35 percent (range 0 to 100) of the area burned. Experience in western Canada with prescribed burning indicates that burning alone does not produce an adequate seedbed for regenerating white spruce (33). In British Columbia, it is recommended that in order to secure adequate white spruce regeneration at least 60 percent of logged areas must have exposed mineral soil seedbeds.⁴ These latter requirements are based on timber management objectives and may be more or less than needed in burned areas, depending on the desired density of the new forest.

Duration of seedbed receptivity is important because of the periodicity of seed years. For some species (white spruce in particular), from 2 to many years may be required to adequately stock an area. Seeding is generally most successful on freshly exposed seedbeds. However, based on data from other areas, seedbeds may be receptive for several years following initial exposure.

Vegetative Reproduction

Vegetative reproduction of several interior species is common. Regeneration from this source has a distinct advantage over seed regeneration because it is not dependent on seedbed conditions and the sprouts or suckers have the root system of the parent tree available as a source of food reserves and for water supply. Obviously, the disadvantage of this process is that the species had to be growing on the site.

White spruce.—Weetman (31) reported a small spruce formed from an adventitious shoot on the parent plant's root system. However, this occurs only rarely and is of no practical importance to reforestation at present.

Black spruce.—This species reproduces vegetatively by layering (15, 10). However, this type of reproduction is probably of little importance to reforestation of burned areas.

Paper birch.—Birch can regenerate by sprouting following logging or fire; however, Hutnik and Cunningham (13) report that this means of reproduction may be uncertain. They cite a study in Maine in which 77 percent of the stumps sprouted but only 16 percent had live sprouts after 8 years. It also seems that the source of sprouts (i.e., buds at base of parent tree) may be susceptible to being killed directly or indirectly by fire. Lutz (16) and Gregory and Haack (9) concluded that seed regeneration predominated over vegetative reproduction for birch in Alaska.

Quaking aspen.—Gregory and Haack (9) have reported that the most common origin of trees of the aspen stands which they studied was believed to be from root suckers. This is generally believed to be the case for aspen in other areas, too (e.g., (26, 8, 2)). Graham et al. (8), Horton and Hopkins (12), and Patton and Avant (23) report examples of abundant aspen suckering following fire. The source of suckers (aspen roots from 1 to several inches below the soil surface) would appear to be much less susceptible to

⁴ Caribou Section, Canadian Institute of Forestry. *Recommended forest practices for the central interior of British Columbia.* (Unpublished.) 29 p., 1969.

damage by burning or high temperatures generated during fires than the source of birch sprouts.

The ability of aspen roots to produce suckers is great. Lutz (16) reported as many as eighty 3-year-old suckers per milacre under a fire-killed aspen. Aspen roots from Alaska trees have produced as many as five suckers per centimeter of root under ideal conditions in the laboratory (see footnote 2). Graham et al. (8) reported young sucker stands with 40,000 to 60,000 stems per acre in the Lake States.

Balsam poplar.—Sucker regeneration of this species following fire is believed more important than seed regeneration (16). Density of suckers and capacity to produce suckers were not found but may be similar to that reported for aspen.

Summary.—Aspen and probably balsam poplar exhibit the greatest ability to reproduce vegetatively. In areas in which these species were components of the prefire forest this probably constitutes the main means of reforestation these species. Although birch has a capacity for vegetative reproduction, it is probably not as important to the species as to aspen in burn reforestation. The importance of vegetative reproduction to black spruce reforestation is unknown but would seem to be much less important than seed reproduction.

Application of Data

These and similar data are useful for both applied and theoretical considerations. Practically speaking, these data provide a quantitative basis for evaluating reforestation potential of burned areas. Thus, an area could be rated using such factors as seedbed conditions, seed source, and others. For example, there is a strong indication that reforestation from seed by any of the interior species may be extremely difficult unless a majority of the area has an exposed mineral soil seedbed. In addition, burned areas farther than 150 to 200 feet from a seed source may not receive adequate seed for the formation of well-stocked stands regardless of seedbed conditions. In addition, there is a possibility that upper-elevation burned areas may be further limited because of limitations on seed maturation during some years. These considerations suggest that manipulation of surface conditions may be required to efficiently utilize the seed available or that artificial seeding or planting may be necessary to supplement or replace natural regeneration on some sites.

These data can also be used in reconstructing past history of burn reforestation. For example, although most forest land is believed to have burned at least once, much of the area has returned to forest cover. This would indicate that, generally speaking, conditions created by fire in conjunction with regeneration characteristics of these species have been adequate to return forest cover to predominance over varying time spans. Lutz (17) has reported a decline in the occurrence of white spruce believed the result of burning. Although this may be due, in part, to misconceptions of the importance of this species by early explorers, the above data indicate that white

spruce in Alaska may be the most poorly adapted species from a postfire reforestation standpoint. In almost every variable considered, white spruce ranks last. Thus, as in other areas, it appears that fires may well have a selective influence on reforestation, with hardwoods being favored to the detriment of white spruce. These selective influences can be traced in part to the factors discussed in this paper, that is, seed, seedbed, and vegetative reproduction variables.

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**Fire and
Resources in
the Subarctic –
Panel Discussion**



Introduction

In preparing for this symposium, discussion inevitably turned to the many facets of wildfire in the subarctic which should be considered—material, philosophical, economic. For instance, how do we put a “value lost” number on a burn north of the Yukon River? What impacts do fire operations have on the economy of Fairbanks? On the economy and village structure of Galena? Of Chalkyitsik, or Unalakleet, or Shungnak? Does the utilization of village fire crews disrupt or alter social structures or native culture? In a more direct sense, if the men of the village spend the summer with a Fairbanks-based fire crew, will high-quality ivory carvings be available for the tourist market?

In a different vein, the entire questions of fire history and the role of fire in subarctic ecosystems remain open for exploration—the pioneering work of H. J. Lutz reinforces the questions. Does fire over permafrost terrain result in melting of the frozen ground from increased exposure to sunlight and increased radiation absorption by blackened surfaces, or might a shallower “active layer” (depth to permafrost) result, as suggested in a recent Russian paper? Do moose benefit from increase of browse species following fire in lowlands? What about water fowl nesting in the same lowlands? Smoke from widespread fires obscures sunlight, impedes scenery-watching, and may curtail military and commercial air traffic—even boat traffic. An acquaintance recalls traveling by river boat from Fairbanks to Minto in August of 1969, and being unable at some points to see either river bank, let alone landmarks, thanks to the thick pall of smoke hanging in the lowlands. Does public policy take full account of this complex of questions about fire’s role?

One could go on with such questions, of course. In any case, it was clear that this symposium would not give “the answer” to the multitude of problems associated with fire. Research results are available on some facets, as preceding phases of this meeting will attest. Other areas are untouched by critical thought, let alone research of any depth.

In this frame of mind, it was resolved that a panel discussion, with time for mutual give-and-take by all symposium participants, might be useful. The title was left as broad as possible—“Fire and Resources in the Subarctic.” The panelists were asked only to share whatever thoughts they felt appropriate, within the framework of their experience, for the benefit of us all.

Charles W. Slaughter
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I wrote a letter to Al Comiskey in response to one he had written to me stating that someone should present a paper at this symposium on how fires affect the economy of native villages. I said I could not present a paper but would serve on a panel discussion. Yesterday Chuck Slaughter caught up with me and said, “You’re on that panel.”

Roger A. Sylvester
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Richard Barney stated previously in his paper that \$3.6 million was earned in firefighters' wages last year in Alaska. The majority undoubtedly went to trained local native crews. At the recent meeting of area foresters of Bureau of Indian Affairs (BIA) in Phoenix, the Albuquerque BIA area forester reported earnings of \$1.4 million and the Billings area reported \$1.4 million in firefighters' wages for 1970. Consequently, there is considerable income going to Indians and Alaska native people as firefighters.

I was given a proposal by Al Comiskey which has been bounced around many times: "Is there any way that we could spread out the sporadic money that the firefighters earn to year-round income?" In recent years, these wages have been of a "boom or bust" nature. Firefighters earned considerable money and sometimes spent it all before they returned to the village. Bureau of Land Management (BLM), the primary employer, has improved the situation somewhat in recent years. It now mails firefighters' checks directly to their village addresses.

In response to the question of firefighters' wages spread out to year-round, ideally as we see it, firefighters' income should supplement another income and not be the main source of annual income. However, in Alaska this money is often the main source of income for many people. In our recent BIA forestry meeting in Phoenix, it was brought out that we were encouraging bad work habits by expecting firefighters to sit around in their villages and wait for a fire rather than search for a year-round job. I don't think this is as true in Alaska as it is in other areas. I can't recall offhand what I said in my letter to Al Comiskey, but the general trend of my thinking on this guaranteed wage was that it is like the national problem; we all talk about "a guaranteed annual minimum wage." Maybe it's communism or socialism, and we in BIA don't wish to encourage such a system if native people can get good year-round jobs.

Some of the basic effects of fire on the native economy I have written down are as follows: Firefighters receive considerable income when it is needed. It is intermittent and it's good. They like the work and to many of them it's a status symbol in the village. I've worked with Indians the last 20 years, including the Apaches and Zunis, and all are very proud of the status they have acquired as firefighters. One of the negative effects of firefighting in Alaska is that when the men are firefighting no one lays in the food supplies for winter or puts up the fish. It has been proved that our BIA welfare assistance load is heavier in winters following a season of good fire income than it is in years with lesser fire income. This also applies to the fishermen; summer money is quickly spent and then the search starts for another source for the winter time. Another negative aspect is that the Government does not withhold income tax from firefighters' wages. (Curt McVee can check me on this.) Most places they have never had withholding statements. This year the Government sent out a few withholding statements and the recipients did not know what to do with them. Another thing, life insurance is rather skimpy.

We who hire, pass firefighters around as bodies rather than people. Two Indian firefighters recently died on a fire in North Cascades National Park. These people had passed from agency to agency; and when they fell in a creek and drowned, investigations showed that they had been without sleep for 36 hours. These are things we somehow hope to improve as years go by. None of the hiring agencies would have counted this incident as 36 hours without sleep as the firefighters had traveled by bus and that counts as sleep time. You will agree that it is pretty hard to count bus riding as sleep time.

We have been trying in our BIA organization and I think Curt has too, to bring Indians into more year-round positions. We are also trying to work something like a shadow program at BIA in all operations so that when we old duffers retire, we will have trained Indian fire control officers and others skilled in running these programs. Some of the native people are shy when it comes to issuing orders to Caucasians, but not all. We hope to build their self-confidence in decisionmaking, for most Indian firefighters have been to more fires than anyone except possibly Ed Komarek. Thank you.

For my part on this panel, I have chosen to introduce to you preliminary data from one of our fire studies conducted last summer in Alaska and in the Yukon Territory. In contrast to most of the other papers, this study deals with a plant community that occurs both in the tundra and in the forested regions of the North. Professor L. C. Bliss and I had been studying plant production on the *Eriophorum* tussock tundra when one of our study sites was burned in the June 24, 1969, fire, at Mile 107, Elliott Highway, Alaska. Plant regrowth was so rapid that we felt it would be valuable to follow secondary succession, provided we could find similar sites that had burned in different years.

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The *Eriophorum* tussock community consists of a matrix of *Eriophorum vaginatum* L. (cottongrass) with heath species and varying amounts of lichens and mosses. It is commonly found as an extensive tundra community from the North Slope of Alaska, east to the Northwest Territories. South of the tundra, it is found in areas of restricted drainage in the taiga. The accompanying soils are acidic, peaty, and often underlain by permafrost.

Four study sites that had been burned for 1, 2, 2, and 4 years were located in 1970. Two of these were true tundra, and two were in treeless peaty soil of the taiga. Measurements of plant cover, active layer depth, seedling density and plant production were made on both burned and unburned communities that were separated by either a road or a fire guard.

The fire in all cases had been severe enough that all aerial woody and herbaceous plant material and the litter were consumed. The tightly packed tussocks were charred but not burned, and little peat was burned. All mosses were killed; but very often, mats of moss were not consumed.

I wish now to assemble the four study sites to discuss the progression of

events as plants reinvaded the area.

Within a few weeks after the fire, we did find some *Eriophorum* regrowth, but this was small and the soil surface began to dry out. When we examined the *Sphagnum* moss and upper peat layers, we found that buds of shrubby plants looked as if they might grow next year. Active layer depth was generally increased in the burned area. An exception to this was under moss patches. Here the dead moss provided insulation and prevented permafrost degradation.

One year after the fire we found a dramatically increased flowering of *Eriophorum vaginatum*. Counts showed that there were three to 10 times more seedheads on the burned area. Some of the other plants began to emerge, but no seed appeared on the other plants. The active layer of the burned sites was deeper than that of the controls. In the spring, the active layer was 35 to 50 percent deeper and in the fall, 15 to 20 percent greater. In other words, the length of the growing season had essentially increased because of earlier spring permafrost melt.

By midgrowing season, most of the vascular species, including the slow-growing ones, had begun to recover. At this point, we also noticed a number of seedlings invading the burned area. *Calamagrostis* and *Arctagrostis* were present, but only the *Eriophorum* seedlings showed high invasion rates (over 200/m²) in the summer. By the next spring, however, very few of the seedlings had survived.

Since we were looking at four areas that had burned at different times, I could piece together the vascular plant production of these areas. The amount of regrowth was nearly 50 percent on the 1-year-old burned area as compared with the control. On areas burned 2 years earlier, there was about 80-percent production compared with the control area. After 4 years, the production of the burned area was 110 percent of the control. Most of this latter increase was due to *Calamagrostis* and *Arctagrostis*. We are now trying to determine why production recovers so fast. Analysis of plant tissue will aid in determining if the nutrient status of the plants in the burned area is much higher.

In summary, we have established that burns tend to be light, at least in this tundra vegetation type, because of the wet soil profile, and no vascular species are completely eliminated by fire. Of course, lichens and mosses are destroyed, and it will take a long time for them to reestablish. At least some plants, such as cottongrass, have a vigorous seed production after fire. This may be due to nutrients released by the fire, or it may be due to translocation of food supplies within rhizomes so that the living portions obtain more stored energy and can produce more seed. Also, there may be a nutritional effect because of a warmer soil profile and a deeper active layer for a longer growing season.

The burned peaty surface is a very harsh site for seedling establishment, and invading seedlings do not contribute much to production. *Calamagrostis*

and *Arctagrostis*, which are part of the original plant community, show the greatest increase and spread after a fire. Other major components of the community also show rapid recovery, and this makes the question of fire frequency on tundra communities difficult to answer. If other tundra communities regrow in similar fashion to the *Eriophorum* tussock community, a burn may be difficult to detect in a very few years after a fire.

There has been considerable discussion regarding resource values and the fact that they are the determinant of the extent of fire control efforts so anything I might add would be redundant at this point. Research, as it relates to the natural ecosystem, has also been most adequately discussed by this group, with numerous innovative ideas being developed. Therefore, I think my time here might be spent in discussion of some future aspects and implications of fire control in Alaska.

Curtis V. McVee
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Land Management
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One of the new legislative tools many of us will have to work with is the Environmental Policy Act of 1969. The act is applicable to "major Federal actions significantly affecting the quality of human environment." We have been searching for a definition of this statement, but this will not occur until there has been some precedent established by the Council on Environmental Quality and the courts.

We in fire control have always assumed our role was environmental protection. This will probably not be sufficient in the future, and we may have to prove our case. I visualize there are two fronts on which we will be questioned—so first let us question ourselves.

First, is fire detrimental to the environment? This may be the case in terms of smoke pollution and the addition of particulate matter to the earth's atmosphere. Fire does also result in degradation of wildlife habitat in some instances and in acceleration of watershed deterioration. On the other hand, it has always been part of natural ecosystems and its elimination may not allow the dynamic ecosystem to properly function.

The second area will relate to our control practices and the question will be, "Are the practices which you employ in controlling wildfires (physical and chemical) affecting the quality of our environment?"

The ability of concerned groups and individuals to bring injunctive proceedings may force a discussion of these issues into the courts, and it will be essential that we have the correct answers.

We in Bureau of Land Management feel that the time is past when public lands can be indiscriminately transferred into private ownership or that resources can be harvested without the benefit of comprehensive plans. Alaska still has opportunities to analyze its options and to formulate land and resource use policies and objectives as it proceeds to develop.

Economic development plans—which in this State are dependent on the

extraction and use of natural resources—must be founded on sound inventories and analysis of resources. Alternatives should be carefully weighed and choices calculated to preserve and enhance resources of the State and Nation.

Built into such plans must be fire control aspects. There is opportunity to plan growth in such a manner so as to minimize both the hazards and the costs of fire control. We don't need a southern California situation with people and property in a high risk area, although, to be sure, this is already the case adjacent to Anchorage and to some extent immediately north of Fairbanks.

We have a big job to do in creating an awareness of the costs of fire control and in working to design land uses to reduce fire control cost and risks. Local planners and zoning authorities can contribute to this effort and, in many instances, hold the key. We know that scattered settlement and strip settlement along the road and highway systems compound problems because any dispersion of fire incidence creates attendant logistical problems.

Currently, the State of Alaska bears the financial cost of controlling fires on State and private lands. On land settlement claims where title has not passed to the claimant, the Federal Government absorbs the cost. Under recent legislation on disaster, the State is eligible for Federal funds when serious fires occur.

I would like to suggest that maybe local governments and, more precisely, property owners assume greater responsibility. I think this is particularly applicable when related to the high man-caused incidences of fire in a State which is as sparsely populated as Alaska.

The institution of a burning permit system as has been proposed by the State and the strengthening of enforcement to eliminate promiscuous burning will reduce fires and probably costs, but the recognition by an individual that carelessness will be reflected in a mill-levy increase may be much more forceful.

I want to talk a bit more about planning. Currently our Anchorage district has been working on a land and resource plan for an 11-million-acre area encompassing the Wrangell Mountains. Part of this process is to define the commercial forest areas, the recreation and scenic areas, wildlife use areas, etc., to assure that resource use conflicts are identified. Choices will have to be made. Out of this will come a multiple-use plan including a description of fire control needs. For example: The wildlife biologists say that an annual loss to fire of over 300 acres in the caribou wintering area south of the Copper River will be detrimental. The recreation specialist will similarly define management policies best suited for recreation management. These are the kind of data the fire control planner needs to use as a basis for designing a responsive program.

We can be assured of the fact there will be more people in Alaska, which will result in more roads and greater dispersion of the population over the

State with increasing demands on public lands and their resources. All of this intensifies the fire control problems.

The symposium of the past 2 days has provided the opportunity for us to be brought up-to-date on the state of knowledge of the effects of fire in the northern environment. Although an excellent start has been made, it is also quite apparent that the available knowledge on the subject is very limited. We have only begun to penetrate what is a very complex ecological relationship.

David R. Klein
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My specialty is wildlife ecology. It is apparent at this point that we in animal ecology are not as far along in understanding fire ecological relationships as are the plant ecologists. What we do know is in the form of generalizations; we lack certain specific information which is essential for proper management. Take, for example, moose, a species which has received considerable attention at the Kenai National Moose Range. We know quite a bit about the relationship of moose to fires, but we really cannot say what is most desirable in terms of the relationship of fire to vegetation in view of long-term benefits to moose. In the case of caribou, we also make generalizations. We know that lichens are a major source of the caribou's winter forage and therefore we know, as Dr. Scotter has pointed out, that fire is quite detrimental to caribou; but Dr. Scotter also alluded to the fact that under some conditions fire may actually stimulate the growth of lichens. There are also indications from work in Scandinavia and the USSR that this may be the case. It is somewhat like looking at fire in relationship to a white spruce tree; obviously fire is detrimental to the individual tree but perhaps it is essential for the well-being of the species. Perhaps fire is analogous to wolf predation on caribou. For the individual caribou that's taken by wolves there is nothing beneficial about wolf predation, but wolves may be beneficial for caribou as a population or a species, and fire may be beneficial for lichens over a long period of time.

In the case of waterfowl in interior Alaska, we have observed in areas such as the Yukon Flats, Minto Lakes, Tetlin Lakes, and Koyukuk Flats that the productivity of these areas for waterfowl seems to be maintained by wide extremes of nature: periodic flooding and periodic fires. Again, I am making generalizations when we need very much more specific information. In the case of fur bearers, we can generalize and say that fires are most often beneficial to fur bearers in that fires usually bring about an increase in biomass productivity in a given area. We know that most fur bearers are near the top of food chain pyramids and that if we broaden the base of these pyramids, we increase the number of animals that can live near the top of the pyramid.

There is not time to go into specifics about wildlife and fire and besides I have already said we lack this type of information. So what I would like to

do in conclusion is to make a few generalizations about fire and resource management and hope that they will stimulate discussion. It has already been emphasized to us throughout the session that fire has multifaceted effects on resources. These can be both positive and negative. It is not necessary to enumerate the various resource values that are involved. Obviously we cannot let all fires burn, nor is it desirable to even attempt to put out every fire. This means we have to make decisions—the question is who is to make these decisions and on what basis. In many cases we have neither the basic knowledge nor the technological competence to enable us to make instantaneous decisions at the time of the fire. Obviously, priorities must be established in advance. Any increase in our present knowledge will allow more intelligent priorities to be established and more realistic fire decisions to be made. Thus the need is very obvious for continued and expanded research.

We also must understand and accept that biases are inherent in all of us. I do not mean just the Smokey Bear complex (which a friend of mine refers to that as “anthropomorphic ursininity”), but what I refer to are human complexes which are more deeply ingrained. Perhaps most important is our man-oriented shortsightedness. Man’s time frame is certainly different from that of nature. As scientists we talk about a 15- or perhaps a 25-year study as being a long-term study. In the case of fire and ecology, we are dealing with changes involving hundreds of years; obviously we are not speaking the same language nor are we in the proper perspective to understand fire in an ecological sense.

Another very important problem associated with man and his biases is in realistically appreciating man’s place in the environment. I think we all here recognize that man is a part of the environment as well as being a product of it. But he is unique among life, being the product of cultural as well as biological evolution. As a result we are compelled, because of our past, to think in terms of cultural as well as ecological values. Sometimes these are not compatible. For example, there are very few of us here that could look upon a newly burned climax white spruce stand and say that such a sight is esthetically pleasing. This is a cultural bias. I’m not suggesting that we do away with cultural biases; on the contrary, these are the very basis for much of the richness in our lives. The important thing is that we must not confuse cultural biases and cultural concepts with what are ecological truths. We should not attempt to justify cultural concepts on ecological bases nor in the name of ecology.

Perhaps I can simplify for you by reference to a hypothetical example. What I am saying in terms of fire ecology is that in a given case if we so highly value a climax spruce stand that we are unwilling to undergo the short-term cultural losses associated with its burning then we should understand the consequences and be prepared to meet them. In short, I think that I am saying something that is akin to what motherhood used to be when population increase was still fashionable; that is, that we should manage our resources in knowledge rather than in ignorance.

A Summation of “FIRE IN THE NORTHERN ENVIRONMENT” and a Suggestion for a COOPERATIVE ECOLOGICAL EXPERIMENT STATION



This symposium on “Fire in the Northern Environment” has been an exciting exchange of ideas. Your chairman has asked that I present a “summation” and some “concluding remarks.” The following summation indicates clearly the need for more research of the proper kind for the intelligent ecological management of fire. The symposium and the preparation of the summation has so stimulated me that for my concluding remarks, I will discuss the formation of a cooperative ecological experiment station for Alaska. The objective of such a station should be to find out ways and means for man to work with nature, not to conquer or subdue her. The purpose of such an endeavor should be to bridge the gap between science and management. It is my earnest hope that the summation and the concluding remarks will spur you and other interested persons toward longtime ecological experimentation and study, not only on fire but also on those phases of ecology that are so badly needed for man to live in a harmonious relationship with the unique Alaska environment.

E. V. Komarek, Sr.
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The Summation

You have listened attentively to the speakers and have participated actively in discussion for the past 2 days. Your presence is indicative of the interest in the subject of fire in the northern environment of over 30 organizations: local, State, and Federal government, private industry, and citizen. Over 100 participants have been gathered here, some from far distances, representing seven States other than Alaska, and Canada. This kind of response certainly emphasizes the widespread interest in Alaskan fire problems.

The sponsors of this symposium, the Alaska Forest Fire Council and the Alaska Section of Society of American Foresters, have contributed much to

the future welfare of this State and, in particular, to this subject, by bringing all of us together to discuss, and even argue, the place of fire in the northern environment. The expressed hopes of these organizations, as well as those of our able chairman, Charles W. Slaughter, and his colleagues, Richard J. Barney and Albert Comiskey, have been fulfilled. The stated purpose of this symposium was

... to explore the many aspects of wildfire in the Alaskan Sub-Arctic ... to delineate and clarify some current questions and opinions on wildfire ... [and] ... its relationship to the natural environment, and to man's use of that environment—as well as to consider some aspects of fire control in this region.

Thirty-one persons have expressed their ideas on fire in 26 papers; this represents more technical papers on fire in Alaska than are listed in Larson's (2) bibliography on fire in the far northern regions. The wide selection of talks and the ensuing discussions have shown not only the broad scope of this subject but also the competence of our chairman and his colleagues. However, the papers, panels, and discussions have revealed several important aspects and paradoxes in relation to fire in the Alaskan environment that must be explored. These are:

1. In interior Alaska, there is only a relatively small acreage that has been designated by foresters as *economic forest land* in comparison with an extremely large acreage classed as watershed, wildlife (game and fish), and *noncommercial forest land*. This, for such a large region in the United States, is a unique condition. Of the 350 million or more acres in the interior basin, more than 230 million acres are identified as tundra, marshes, bogs, rivers, and *nonforest lands*; about 80 million acres are classed as *noncommercial forest land*; and only about 40 million acres are designated as *economic forest land*.

The primary usage and management therefore cannot be for the commercial production of forest wood products. Thus, methods, ideas, and philosophies that are primarily forest-oriented, either commercially or ecologically, must only be used with the utmost caution in the use, management, and development of most of this unique region.

2. Interior Alaska, because permafrost underlies much of the interior basin, is ecologically different from most other regions. It is a unique area, a "never-never land" for it is neither soil, nor water, nor ice, but a variable mixture of all three. Methods of investigation and analysis developed in other regions may not be valid under the conditions existing in this area.
3. The interior basin, because it is a wet region but with a semiarid climate, is a paradox. This situation in connection with the existence of the underlying permafrost certainly creates unique ecological circumstances. The results from studies on fire effects and processes conducted elsewhere may not always apply here.

4. Solar radiation in interior Alaska, because of the long sunlit days in summer and virtually no sunlight in winter, creates conditions much different from those in more temperate climates. An example (7) of this is the following:

...relationship of soil temperature to forest cover in northern regions contrasts with that of temperate regions where frost penetration is greatest under nonforested areas and far less or lacking under forests.

5. Several papers at this symposium have shown the very fragile nature of the vegetative cover in the interior basin which if disturbed or destroyed allows severe erosion to develop, resulting in accelerated and permanent damage. Data have been produced indicating that fire-fighting methods in this region must be adapted to the conditions existing here and conducted in a manner different from those used in other areas.
6. Interior Alaska is a natural lightning fire environment, and the plants and animals are adjusted to fire. However, the effect of man's interference by either fire-exclusion or overburning is virtually uninvestigated. Studies made in other regions cannot always be put to practical use in this region because of the previously mentioned unique conditions even though basic ecological principles apply.
7. Studies on the impact of fires on the habitat of large mammals show the need for longtime studies in such a region as interior Alaska. Investigations on the frequency, intensities, and kinds of fire and their effect on the environment over a long period of time are non-existent. An example of the differences that occur is the following. In recent years, two excellent investigations into the life history and habitat of the caribou have been made; one on the barren-ground caribou in the Northwest Territories by Scotter (4, 5) and another by Skoog (6) on the Alaskan caribou in Alaska. Some of the differences that arise are well brought out by Scotter (5) as follows:

Skoog (1968) concluded that range destruction by fire had little influence on known caribou populations fluctuations in Alaska. He stated that losses of range due to fires were greatly mitigated *because caribou were not dependent for forage upon lichen growths in spruce forests*. Forages in other communities such as tundra, alpine meadows, and other areas could be utilized. He considered doubtful that fires had much influence on fluctuations in caribou numbers in Alaska.

There is a marked contrast, however, between much of the winter range used by barren-ground caribou in Canada and the winter range used by caribou in Alaska. If a winter range burned in the relatively flat taiga of northern Canada it might cause caribou to move miles in search of food; in

Alaska, the caribou might merely have to move a short distance up the mountain side into the alpine region to find lichens and other forage to meet their nutrient requirements. (*italics* Komarek's)

A review of these two studies shows that they are concerned with two entirely different conditions. Likewise, we are dealing with two different subspecies of caribou, the barren-ground caribou (*Rangifer tarandus groenlandicus*) and the Alaska caribou (*Rangifer tarandus granti*). I (*1*) have mentioned that the wide ranging migrations, particularly of the barren-ground caribou, might well be, at least in part, an "adaptation" to widespread fires. Fires certainly play a large part in the movements and migrations of some of the large ungulates in Africa.

8. We have listened to excellent papers on the effect of fires on the quality of the water environment that highlight the need for long-term investigations in the interior basin. Little appears to be known about nutrient recycling by fire into the streams and lakes of this region. In southeast States, a common practice based on extensive investigations is the fertilizing of fish ponds with such nutrients as potash, phosphate, and lime. What kind of fires, how frequent, etc., produce the same result in nature? Studies of watersheds where fire has been excluded for a long period by man and then burned by wildfire under drastic climatic conditions are not investigations of natural events.
9. No investigations of any serious nature have been made on the effect of fires upon the habitats of the waterfowl that frequent interior Alaska. What kind of fires, and how frequent, produce the best conditions for waterfowl? It is a regular practice on many waterfowl refuges from southern Canada to the Gulf of Mexico to use controlled burning in the successful management of the habitat for many species of waterfowl. Recent studies at the Northern Prairie Research Center at Jamestown, North Dakota, show the intricate relationships of fire not only with food production but with predation on nesting grounds as well. Under certain vegetative conditions, predation on duck nests is exceedingly high. This predation is lowered extensively by properly controlled burning.
10. The study and use of controlled or prescribed burning, except as it pertains to slash burning from clearcutting, is conspicuous by its absence not only in this symposium, but in the literature. Common sense would dictate its proper use if for no other reason than hazard control and safeguarding homes, installations, and economic forests. Interior Alaska is a natural fire environment and thus fire is part of the wildlife habitat. However, with the increasing development of this region, it may become necessary for the use of control burning on an extensive scale. Large regions in both Africa and Australia are burned regularly: by ground application and for game or other wildlife

purposes in the former; by aerial application for silvicultural and wildlife purposes in the latter. Aerial application of controlled burning might well be applicable to interior Alaska.

The Suggestion

A COOPERATIVE ECOLOGICAL EXPERIMENT STATION FOR ALASKA

Alaska will grow and progress as have all the other States, for Alaskans have no desire to remain a pioneer or wilderness State, at least not entirely. Its population will increase, its cities will enlarge and new urban areas develop, and its industries will not only grow but multiply as well. Thus the question is, how best can this development and growth be guided with the least disruption of the natural environment and for man's own welfare as well?

The inhabitants of the lower 48 States are in no position to single out Alaskan problems when their own environments are rapidly being destroyed by burgeoning expansion of urban, industrial, recreational, and highway developments. Alaskan development, like its research and problems, must in the main be solved by its own peoples. As pointed out in the summation, this is particularly true for Alaska because of the uniqueness of its natural environment. However, the lower States can serve as an example, for both good or bad as the case may be, to the future direction and guidance of Alaska.

One of the "good" examples from the lower States which has already been introduced is the State Agricultural Experiment Station at Palmer, Alaska. The creation and development of the system of State Agricultural Experiment Stations in the late 1800's has materially assisted the Nation in becoming the leading food producing country. This agricultural productiveness and technology was created by *experimentation* by both the agricultural stations and the farmers as well. This agricultural foundation, in turn, made it possible for the rapid industrialization of the Nation. The problems of pollution of our environment today are the result of rapid technology and consequent urban growth without guidance or direction by *industrial or urban experiment stations*. It is time we enlarge upon the time-tested experiment station approach and apply it to the *ecological management* of the world in which we live, instead of limiting it only to agricultural production. It is with this idea in mind that I suggest to you the creation and development of a cooperative ecological experiment station for interior Alaska modeled in many respects after the successful pattern of the agricultural experiment stations.

Purpose.—The purpose of an Alaskan cooperative ecological experiment station should be to seek and develop facts and other information by *scientific experimentation* on the relationship of man and his objectives to Alaska's unique natural environment. There is a great need for facts, not

opinions, on how to successfully manage, direct, and conduct, as well as cope with, the growth and industrial expansion in Alaska. The objective of the Station should not be to *conquer* nature but to find out ways and means for man to *work with* nature. The purpose should be to bridge the gap between science and management.

Science and management.—This objective is difficult to reach because of certain inherent differences between science and management. Science is the accumulation not only of facts, however, but also of the understanding of the principles upon which our natural environment operates. Science is not an attack on a problem but a search for an understanding of the ecological complexities and a realization of the variations in nature. Management, on the other hand, is not a science but an art, for it is the “judicious use of means to accomplish an end.” Facts and information from science must be taken and weighed in comparison with the objectives of management. This ultimately means that the solution is reached by compromise. Much of the argument between environmentalists and industry today is because facts are few and there is little understanding of the ecological diversity and complexity in nature.

I have chosen the title Cooperative Ecological Experiment Station with care and each word in it designates an important function of such an endeavor. These words have been placed in that juxtaposition for semantic's sake but in importance they should be emphasized as experiment, cooperative, ecological, and station, and I will discuss them in that order.

Experiment.—Let me make clear to you at the onset that I consider the approach and methodology of an ecological experiment station as quite different from that of the usual biological station, ecological institute, or research center. An experiment station is “where experiments are tried, studies of a practical value made, and information disseminated” (3). An experiment is an “act or operation undertaken in order to discover some unknown principle or effect, or to test, establish, or illustrate some suggested or known truth” (3). To experiment is the “action of trying or testing; the conducting of a test or a series of tests” (3). Thus, the basic purpose of an ecological experiment station must be the idea of manipulation, of testing, of experimentation, not just the observance or censusing of plants or animals and their behavior, or the study of the life history of an organism. To illustrate my meaning to you, let me give you the following example.

An ecological experiment station not only would study the effects of fire on plants, animals, soils, etc., caused by a wildfire but would in addition set up sizable plots which would be studied in their entirety to be reasonably positive that they were comparable. These then would be burned at various intervals such as annually, every third year, every fifth year, and so on. Some plots would be used as controls and fire would be rigidly excluded; others would be treated or manipulated with severe fire, or cool or feeble fires; and still others would be mowed, bulldozed, herbicided, and bush-and-tree-chopped in a manner comparable to the operation now going on at the

Russian River Burn. I cannot help but wonder at the effect of the latter type of "reconstruction" at the Kenai Wildlife Refuge on the soils, vegetations, and animal life for I know of no parallel or experimentation or study of such a vast operation in the far north. The experimental plots should be maintained for a long period of time—over 100 years.

At the Tall Timbers Research Station, we have a series of 84 "Stoddard" fire plots under various frequencies of fire along with plots where we hope fire will be excluded for over 100 years. Although these plots are only 12 years old, they are already being utilized for studies not only by our staff but by other investigators because they have a *known* history. The ecologist, if he wishes to understand the environment in which man lives, must test; he must manipulate and not only observe.

Cooperative.—The operation of an ecological experiment station must, if it is to realize its objectives, be cooperative because of the complexities in nature. Close cooperation must be maintained between specialists, scientists in other fields of science, as well as with agencies, organizations, institutes, and the public and industry. No such station could develop a large enough staff to operate alone. The State agricultural experiment stations have developed very valuable and extensive cooperative efforts with public and private agencies and with farm groups and farm industries as well.

The close cooperation of a State cooperative ecological experiment station in Alaska with Federal agencies would be essential because of the large acreages in Federal ownership. Close liaison would be necessary with such valuable but more or less specialized agencies such as the Institute of Northern Forestry, Arctic Institute of North America, Cold Regions Research and Engineering Laboratory (CRREL), and the many research and teaching units of the University of Alaska. However, it should be made clear that an ecological experiment station is not a training ground for graduate students; rather, its primary purpose is longtime experimentation directed by a trained staff whose entire time would be taken up with research.

Cooperative effort with private and public industry must be achieved, for the purpose of such a station is to furnish facts and information so that man and his technology can live in harmony with the natural environment. The agricultural experiment stations have achieved this close cooperation with both the public and industry in a most remarkable manner. An ecological experiment station such as I visualize will fall short of its goal if all it does is accumulate information that is not usable to man and his technology.

Ecological.—In many respects an ecological experiment station is quite different from its counterpart, the agricultural experiment station. The latter's primary objective is increased economic food and fiber production, whereas the former's goal is to seek ways and means for man and his pursuits to live in harmony with his natural environment. Ecology deals with the mutual relations between organisms and their environment, and man is part of this affiliation. An ecological experiment station strives to make this relationship a mutual alliance, not a discordant conflict. The habitat of man

includes all of the natural surroundings and influences that affect the development of living things, and it is to mankind's longtime benefit to live in harmony with these surroundings and influences. To accomplish such a harmonious relationship, man must experiment, must manipulate on an experimental basis, before undertaking large projects that may inhibit or destroy such a beneficial condition.

Station.—An Alaskan cooperative ecological experiment station must have permanently owned land upon which to conduct longtime experiments. It must not be swayed from its main purposes by utilizing lands that are already set aside for other uses, for its goal is not increased economic production of food and fiber although there will probably be useful "spin-offs" from ecological experiments useful to such production. The station should be located on land that is underlain with permafrost so that this condition can be observed regularly by the staff. Sub- or field-stations can be located in areas of semipermanent permafrost conditions as well as in permafrostfree regions. It should be apparent that sufficient land must be set aside for experimental investigations because longtime experiments will of necessity occupy much land for a long period. The station by cooperative agreements can also conduct some experimental studies on lands held by other agencies and for other purposes, but the station's primary objective should always be in mind: man's harmonious relationship with nature and how best to achieve this desirable state. The station for many reasons should be located near Fairbanks, thus easily accessible not only to the city but to the many agencies, institutes, and the university as well.

Staff.—Land, buildings, equipment, or ideas will not achieve by themselves the alliance with nature we wish. Of greatest importance to an ecological experiment station must be a competent staff with an ecological outlook. It will be difficult to find imaginative and creative scientists, particularly among ecologists, who have what is called a practical viewpoint. Unfortunately, it has been the custom in certain scientific circles, particularly academic, to frown upon or look down upon, investigations that have an applied or practical application. This appears to have been especially true among natural scientists and ecologists. This attitude of mind has usually been coupled with the need for more and more "basic research," but I fear that at least at times the scientist has only done what he wanted to do. Likewise in such research it is difficult to tell whether or not anything is accomplished regardless of how much money is spent. A review of current literature and dissertations in the natural science or ecological field shows a lack of appreciation for experimental methods on the ground over a long period of years, particularly in the form of replicated plots, controls, and various methods of manipulation of the vegetative cover or of the animal populations. Thus a staff for an ecological research station must be chosen with care for the prime objective of the investigations is information to be used in the wise management of this unique arctic environment. If practical results are not forthcoming, the policies must be reviewed and altered to meet this objective. The development and use by man of the arctic regions

will not be stayed. Therefore, the early establishment of a cooperative ecological experiment station for Alaska is imperative for guidance in this development and use.

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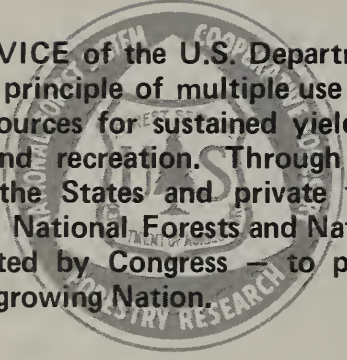
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2. Development and evaluation of alternative methods and levels of resource management.
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